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ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Radioactive Materials Handling Techniques, contains eight modules: Glove Box Operations: Fundamentals: Glove Box Operations: Advanced: Master/Slave Manipulators: Fundamentals: Master/Slave Manipulators: Advanced: Remote Sampling Techniques: Radioactive Waste Disposal Procedures: Packaging and Monitoring of Radioactive Materials for Shipment: and Maragement of External Radiation Contamination. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter, exercises, materials, procedures, data tables, reference materials, and tests. (A master index and suggested program planning guides are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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ED192107

Nuclear Technology Series

COURSE 25

RADIOACTIVE MATERIAL HANDLING TECHNIQUES

CENTER FOR OCCUPATIONAL RESEARCH
AND DEVELOPMENT
4800 LAKEWOOD DRIVE
WACO, TEXAS 76710

CE 026 665

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AUG 1980

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PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules – developed for use in two-year postsecondary technical institutions to prepare technicians for employment – are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert/experienced writer team and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.
Module Prerequisites, which identify the material a student should be familiar with before studying the module.
Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.
Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.
Exercises, which provide practical problems to which the student can apply this new knowledge.
Materials, which identify the equipment required to complete the laboratory procedure.
Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.
Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.
Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.
Test, which measures the student's achievement of the prestated objectives.

A helpful Index has been added at the end of each course.

The materials contained herein were developed pursuant to a contract with the Office of Education, U.S. Department of Health, Education and Welfare: Contract No. 300780582. Contractors undertaking such projects under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official Office of Education position or policy.

The Nuclear Technology Series consists of five curricula:

Nuclear Reactor (Plant) Operator Trainee.
Radiation Protection Technician.
Nuclear Materials Processing Technician.
Nuclear Quality-Assurance/Quality-Control Technician.
Nuclear Instrumentation and Control Technician.

The completed Nuclear Technology Series consists of the following 35 technical specialty courses:

Radiation Physics.
Radiation Protection I.
Principles of Process Instrumentation.
Heat Transfer and Fluid Flow.
Introduction to Nuclear Systems.
Instrumentation and Control of Reactors and Plant Systems.
Reactor Operations.
Reactor Safety.
Reactor Auxiliary Systems.
Power Plant Systems.
Radiation Detection and Measurement.
Reactor Physics.
Power Plant Chemistry.
Introduction to Quality Assurance/ Quality Control.
Metallurgy and Metals Properties.
Mechanical Component Characteristics and Specifications.
Radiation Protection II.
Radiological Emergencies.
Radiation Shielding.
Radiation Monitoring Techniques (Radiochemical).
Radioactive Materials Disposal and Management.
Advanced Radionuclide Analysis.
Nuclear Chemical Processes.
Nuclear Systems and Safety.
Radioactive Material Handling Techniques.
Nondestructive Examination (NDE) Techniques I.
Metrology.
Welding Inspection.
Civil/Structural Inspection.
Mechanical Inspection.
Quality-Assurance Practices.
Nondestructive Examination (NDE) Techniques II.
Control Systems I.
Control Systems II.
Power Plant Electrical Systems and Components.

Availability: Instructional modules are available individually or by courses from:

Center for Occupational Research and Development
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Waco, Texas 76710
Telephone (817) 772-8756

Printed:

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MODULE 25-6 Radioactive Waste Disposal Procedures

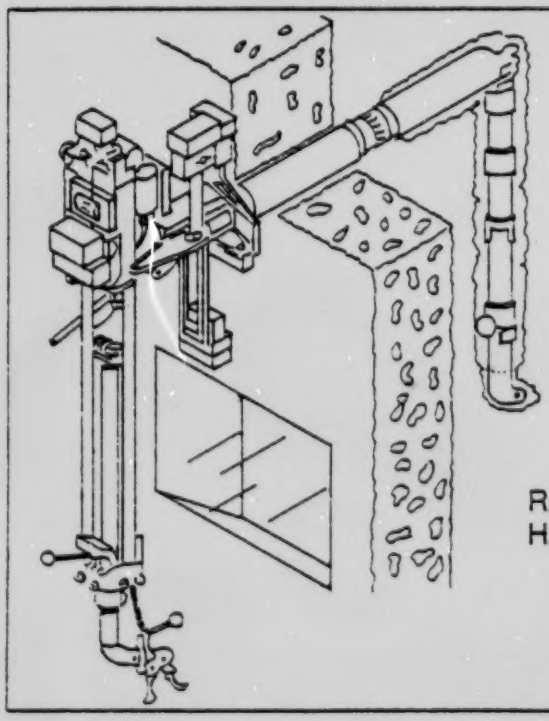
MODULE 25-7 Packaging and Monitoring of Radioactive Materials for Shipment

MODULE 25-8 Management of External Radiation Contamination

NUCLEAR TECHNOLOGY

MODULE 25-1

GLOVE BOX OPERATIONS - FUNDAMENTALS



RADIOACTIVE MATERIAL
HANDLING TECHNIQUES

COURSE 25

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1 Glove Box Operations - Fundamentals
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INTRODUCTION

A glove box is, essentially, a controlled-atmosphere chamber. Equipped with protective gloves and operated at a slight negative pressure differential, glove boxes have been used in laboratories for many years to perform such diverse tasks as to handle radioactive and nonradioactive hazardous materials, to provide sterile and dustfree environments, to handle toxic biological agents, and to surround oxygen-sensitive materials with an inert atmosphere. Samples of materials brought back from the moon were handled inside glove boxes. More routine uses include the day-to-day handling of radioactive material by technicians in radiochemical laboratories.

Inside these laboratories, glove boxes allow technicians to contain and handle alpha-emitting or low-energy beta- or gamma-emitting radioactive materials. Their use is routine, and technicians are expected to be proficient in their safe and proper operations.

This module, as an introduction to glove box operations, describes glove box design and construction. It also provides detailed information on basic safety equipment and procedures for safety in glove box operations.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; and Course 17, "Radiation Protection II."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Describe the design features of a typical glove box, emphasizing the features designed to prevent contamination of the laboratory.
2. List safety features of a typical glove box.
3. Given a stated quantity of nuclear material and appropriate tables, find the type of laboratory in which the material may be handled safely.
4. Give several examples of the type of work carried out in each of the following zones and the amounts of nuclides allowed in each:
   - Clean zone.
   - Regulated zone.
   - Contamination zone.
   - Limited-access zone.
   - Radiation zone.
5. Discuss why the equipment and procedures listed below are used for personnel exposure control around glove boxes:
   - Film badges.
   - Pocket dosimeters.
   - Bioassays.
   - Alpha counters and monitors.
   - Hand and foot counters.
6. Describe typical administrative preliminary procedures for a glove box operation, including –
   - Preparation of Problem Safety Summary.
   - Special procedures for fissile materials.
   - Posting of log sheets and preparation of labels.
7. Given necessary dress and equipment, properly dress out for glove box operations.

8. Place material in glove box, using –
   Sphincter valve.
   Air lock.
   Describe the limitations of each of these methods.
9. Perform bag-in and bag-out procedures.
10. List and describe general glove box safety rules.

GLOVE BOX DESIGN AND CONSTRUCTION

Although glove boxes often are designed to meet the needs of particular operations, certain design features are universal. All gove box systems include a sealed enclosure (the glove box); an air, or gas, intake and exhaust system; a means of introducing material into the glove box and getting material out; a means of handling material in the box; and a means of controlling the atmosphere in the box. Figure 25-1-1 illustrates a typical glove box used to handle alpha-emitting radioactive material.

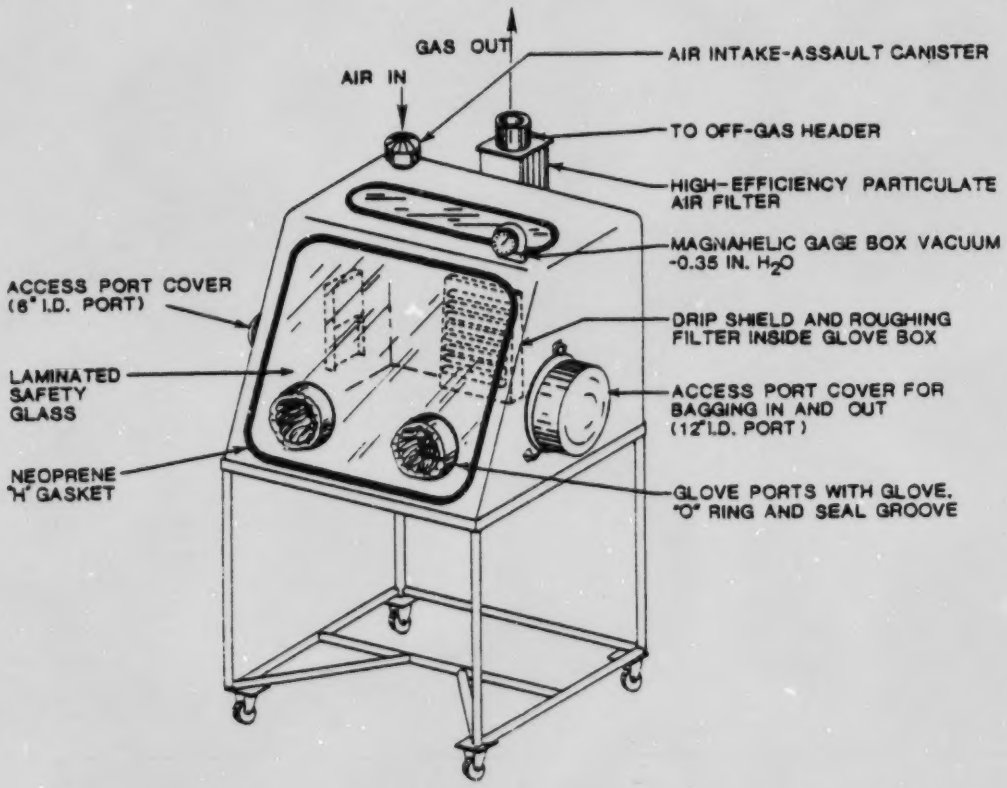

GAS OUT
AIR IN
AIR INTAKE-ASSAULT CANISTER
TO OFF-GAS HEADER
HIGH-EFFICIENCY PARTICULATE AIR FILTER
MAGNAHELIC GAGE BOX VACUUM -0.35 IN. H_2O
ACCESS PORT COVER (8" I.D. PORT)
DRIP SHIELD AND ROUGHING FILTER INSIDE GLOVE BOX
LAMINATED SAFETY GLASS
ACCESS PORT COVER FOR BAGGING IN AND OUT (12" I.D. PORT)
NEOPRENE "H" GASKET
GLOVE PORTS WITH GLOVE, "O" RING AND SEAL GROOVE

Figure 25-1-1. Typical glove box.

The glove box frame is constructed of stainless steel. The viewing face and top panel are made of laminated safety glass and are attached to the frame by a neoprene "H" gasket. Protective gloves are made of neoprene or hypalon and are secured to the glove box with "O" rings and a metal clamp ring (Figure 25-1-2).

Figure 25-1-2. Glove box glove and O-ring.

The glove ports are fabricated in such a manner that a glove can be replaced without breaking containment. There are two access ports (6" and 12" inside diameter), called "bag out" ports, through which material is introduced into the box ("bagging in") or to remove material from the box ("bagging out"). Air is introduced into the box through an absolute filter. The intake air flow varies with the type of filter installed on the glove box. The glove box atmosphere is exhausted through the drip shield and roughing filter. Gases pass through this filter to a high-efficiency particulate air filter (designated HEPA) located outside the glove box. Gases then are passed to an off-gas system that further filters and purifies them before they are exhausted. The differential Magnahelic gage

located in front of the box measures pressure of the glove box relative to pressure in the laboratory. Atmosphere in the box is maintained at a slight negative pressure so that, if a "leak" occurs, air from the laboratory will flow into the box instead of gases in the box leaking into the laboratory. All filters are removable.

The glove box depicted in Figure 25-1-1 is only typical. Some glove boxes contain many other features. One feature often found is the sphincter valve (Figures 25-1-3 and 25-1-4). This valve, sometimes referred to as a "drop box," is essentially another access port and consists of a series of neoprene washer-shaped gaskets separated by spacers made of Plexiglas. It is used to transfer small items into the glove box.

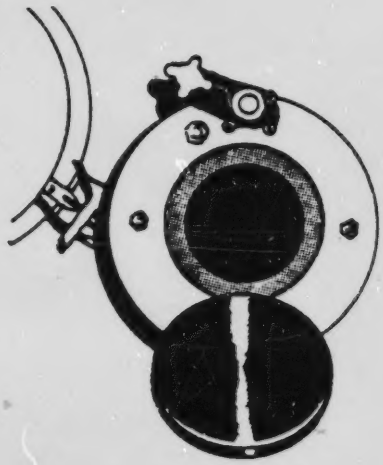


Figure 25-1-3.
Sphincter valve open.

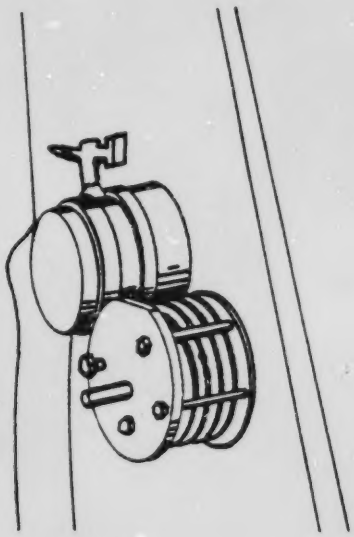


Figure 25-1-4.
Sphincter valve closed.

SAFETY FEATURES

A number of provisions for safety of the operator are an essential part of glove box design for radioactive operations. General considerations for box design include –

- Convenience.
- Good lighting and viewing.
- Good ventilation.
- Safe and efficient working height.
- Fire and corrosion resistance.
- Provisions for maintaining correct atmosphere and pressure.
- Ease of decontamination and disposal.
- The safe and efficient entry and exit of materials.
- The need for heat detectors, fire and radiation alarms, fire control systems, electrical safeguards, gas and vapor analyzers, and other equipment.

Usually, each facility will provide criteria that must be applied to glove box systems before they can be approved for use. These criteria usually are very stringent, and exceptions are rarely, if ever, made.

LABORATORY SAFETY

In every radiochemical laboratory, a system of control and regulation has been established to ensure the safety of laboratory personnel and to avoid release of radioactive material. The technician is responsible for safe glove box operations.

Radiochemical laboratory safety procedures are designed to prevent inadvertent release of radioactivity and to prevent a nuclear criticality accident. Additionally, safety procedures must be designed and equipment installed to prevent and react to the variety of accidents, such as fires and explosions, that can occur in any chemical laboratory.

RADIOCHEMICAL LABORATORY REQUIREMENTS

Although hazards from both conventional and radiation contamination and nuclear criticality must be considered when safety procedures are set up for the radiochemical laboratory, radiation control and nuclear criticality safety are paramount because of their complexity. The radiation hazard can be divided into two categories: (1) the hazard posed by the ionizing radiation itself, and (2) the hazard posed by the spread of contamination by the penetration, ingestion, or inhalation of radioactive material. The radiation hazard frequently is the least difficult of the two to handle and is handled by installation of proper shielding. The spread of contamination usually is more difficult to deal with and may be prevented by use of equipment (glove boxes) designed to contain radioactive particles, by proper laboratory design, and by the application of a system designed to match the relative radioactivity of an isotope with the use of facilities and equipment designed to contain that isotope safely.

Tables 25-1-1 and 25-1-2 provide the basis for such a system. Table 25-1-1 classifies isotopes according to their relative radiotoxicity, based upon inhalation hazard.

TABLE 25-1-1

CLASSIFICATION OF ISOTOPES ACCORDING TO RELATIVE RADIOTOXICITY BASED ON INHALATION HAZARD* AMOUNTS (CURIES) EQUIVALENT TO ONE GRAM OF ^{239}PU (HEP)

Class 1 (Very high radiotoxicity) HEP < 0.07	^{90}Sr + ^{90}Y, ^{210}Po, ^{210}Po + ^{210}Bi, ^{226}Ra, ^{228}Th, ^{232}U, ^{236}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Am, ^{242}Cm, ^{243}Am, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm, ^{247}Cm, ^{249}Bk, ^{249}Cf, ^{250}Cf, ^{251}Cf, ^{252}Cf
Class 2 (High radiotoxicity) HEP = 0.86-17	^{22}Na, ^{32}P, ^{45}Ca, ^{46}Sc, ^{48}V, ^{59}Fe, ^{58}Co, ^{60}Co, ^{63}Ni, ^{65}Zn, ^{85}Rb, ^{89}Sr, ^{91}Y, ^{95}Zr + ^{95}Nb, ^{103}Ru, ^{106}Ru + ^{106}Rh, ^{105}Ag, ^{110}Ag, ^{109}Cd + ^{109}Ag, ^{115}Cd, ^{114}In, ^{113}Sn, ^{122}Sb, ^{124}Sb, ^{125}Sb, ^{131}I, ^{134}Cs, ^{137}Cs + ^{137}Ba, ^{140}Ba + ^{140}La, ^{144}Ce + ^{144}Pr, ^{147}Pm, ^{151}Sm, ^{152}Eu, ^{154}Eu, ^{170}Im, ^{181}Hf, ^{182}Ta, ^{192}Ir, ^{203}Hg, ^{204}Tl, ^{210}Bi, ^{211}At, ^{233}U, ^{234}Th + ^{234}Pa, ^{237}Np, ^{242}Pu
Class 3 (Moderate radiotoxicity) HEP = 22 220	^{7}Be, ^{24}Na, ^{35}S, ^{42}K, ^{47}Ca, ^{47}Sc, ^{48}Sc, ^{52}Mn, ^{54}Mn, ^{56}Mn, ^{56}Co, ^{72}Ga, ^{74}As, ^{76}As, ^{77}As, ^{75}Se, ^{82}Br, ^{85}Sr, ^{90}Y, ^{95}Nb, ^{99}Mo, ^{103}Pd + ^{103}Rd, ^{105}Rh, ^{109}Pd, ^{111}Ag, ^{115}Cd, ^{122}Sb, ^{127}Te, ^{131}Ba, ^{140}La, ^{141}Ce, ^{142}Pr, ^{143}Pr, ^{147}Nd, ^{166}Ho, ^{153}Sm, ^{170}Ho, ^{177}Lu, ^{181}W, ^{185}W, ^{187}W, ^{183}Re, ^{186}Re, ^{191}Os, ^{190}Ir, ^{192}Ir, ^{194}Ir, ^{191}Pt, ^{193}Pt, ^{196}Au, ^{198}Au, ^{199}Au, ^{197}Hg, ^{200}Tl, ^{201}Tl, ^{202}Tl, ^{227}Ac, pure ^{233}U, ^{235}U
Class 4 (Slight radiotoxicity) HEP > 430	^{3}H, ^{14}C, ^{18}F, ^{36}Cl, ^{37}A, ^{51}Cr, ^{59}Ni, ^{71}Ge, [illegible], ^{99}Tc, ^{99}Tc, ^{97}Ru, ^{103}Rh, ^{129}Te, ^{129}I, ^{131}I, ^{133}Xe, ^{203}Pb, ^{235}U, ^{235}U, Th-natural, ^{238}U, U natural

*Isotopes underlined are fissile isotopes, and a nuclear criticality safety review must be undertaken before operations are begun.

Table 25-1-2 relates the radiotoxicity and quantity of an isotope to the type of laboratory in which that quantity of isotope can be handled safely.

TABLE 25-1-2

TYPE OF LABORATORY WITH
QUANTITY HANDLED VERSUS RADIOTOXICITY

Radiotoxicity of Isotopes	Type A High Level Laboratory	Type B Radiochemical Laboratory	Type C Good Chemical Laboratory	Type D Good Chemical Laboratory
Very high	> 10 mCi	10 μCi – 10 mCi	0.1 μCi – 10 μCi	0 – 0.1 μCi
High	>100 mCi	100 μCi – 100 mCi	1.0 μCi – 100 μCi	0 – 1.0 μCi
Moderate	> 1 Ci	1 mCi – 1 Ci	10 μCi – 1 mCi	0 – 10 μCi
Slight	> 10 Ci	10 mCi – 10 Ci	100 μCi – 10 mCi	0 – 100 μCi

The example below illustrates how Tables 25-1-1 and 25-1-2 are employed.

EXAMPLE

Given: A 9-mCi quantity of ^{90}Sr.

Find: The type of laboratory in which the material may be handled safely.

Solution: From Table 25-1-1, ^{90}Sr is a Class 1 material (very high radiotoxicity). From Table 25-1-2,

a 9-mCi quantity of a material of very high radiotoxicity can be handled safely in a Type "B" radiochemical laboratory.

Table 25-1-3 lists requirements for each laboratory type.

TABLE 25-1-3
DEFINITION OF LABORATORY TYPES

Definition of Laboratory Types – Unless otherwise stated, the requirements of a basic laboratory or equal facility are understood.

Type A: Operations to be conducted in glove boxes or hot cells in facilities specifically constructed for handling of high levels of radioactive materials. Containment features must prevent spread of activity within, or release from, the facility. Complete isolation (physical separation) from neighboring facilities, laboratories, offices, etc., is necessary. The use of Plexiglas, Lexan, Homolite or similar materials as a primary or secondary containment barrier is forbidden because of fire hazard. Air locks, whether permanently or temporarily affixed to the glove boxes, shall not be constructed of these materials.

Type B: Operations must be conducted in approved glove boxes. Air inlet and discharge ports must be

fitted with high-efficiency filters, and ventilation air from laboratories containing glove box operations must also pass through high-efficiency filters. Glove box safety features, air locks, and bagging techniques are a necessity. The use of Plexiglas, Lexan, Homolite or similar materials as a primary or secondary containment barrier is forbidden because of fire hazard. Air locks, whether permanently or temporarily affixed to the glove boxes, shall not be constructed of these materials. A degree of isolation, such as hot change facilities or air locks to prevent the spread of contamination to surrounding offices or laboratories, must be maintained.

Type C: Operations must be conducted in approved chemical hoods vented through high-efficiency filters. Hood openings must have a minimum face velocity of 100 fpm; however, 200 fpm may be required for various hazardous operations, especially if hot plates, aspirators, or Bunsen burners are employed. Flame-resistant Plexiglas (Type SE-3) may be used as a containment barrier for Type C laboratory operations, provided approval of the Radiation Control Offices and Safety and Radiation Control is obtained in advance.

Type D: Bench-top operation normally is satisfactory. Hood operations should be considered for upper levels of activity.

The physical form of the radioactive materials and the complexity of the procedures to be followed may increase or decrease the degree of hazard in the handling of radioisotopes. Table 25-1-4 lists modifying factors that can be applied to the values in Table 25-1-2 according to the complexity of operations involved.

TABLE 25-1-4
OPERATIONAL FACTORS TO MODIFY TABLE 25-1-2

Operation	Modifying Factor
Storage	x 100
Very simple wet operation	x 10
Normal chemical operation	x 1
Complex wet operations with risk of spills and simple dry operations	x 0.1
Dry and dusty operations and those where isotopes are evolved as gases	x 0.01

These factors normally apply in B-type and C-type laboratories.

LABORATORY ZONING

Radiation contamination control also is provided by formal zoning of areas in which the radiation dose rates (or radioactive contamination) reach certain levels. Buildings that have radioactive material in glove boxes usually

are divided into four zones: a clean zone, a regulated zone, a contamination zone, and a limited-access zone.

- Clean Zone. Radioactive materials are not permitted in this zone, nor is one permitted to enter wearing the special "contamination" clothing required in contamination and limited-access zones. Clean zones usually include offices, office corridors, rest rooms, locker rooms, lunch rooms, and most of the surrounding area outside the building.
- Regulated Zone. Materials that contain alpha-emitters properly confined, with no surface contamination, may be transported through this zone. Contamination clothing free of contamination or personal clothing, may be worn in a regulated zone. Usually, part of the change room, part of the outside of a building, and other work areas in the building are regulated zones. (See Figure 25-1-5d.)
- Contamination Zone. A contamination zone is a potentially contaminated area in which low levels of radioactive material are permitted and contamination clothing is required.

  Minimum clothing requirements are (a) contamination coveralls or contamination lab coat; and (b) yellow shoes or shoe covers over personal shoes (see Figure 25-1-5c & e).
- Limited-Access Zone. Limited-access zones are laboratories where work with radioactive materials in a glove box takes place. Contamination clothing is required, and additional special requirements are posted at each entrance.

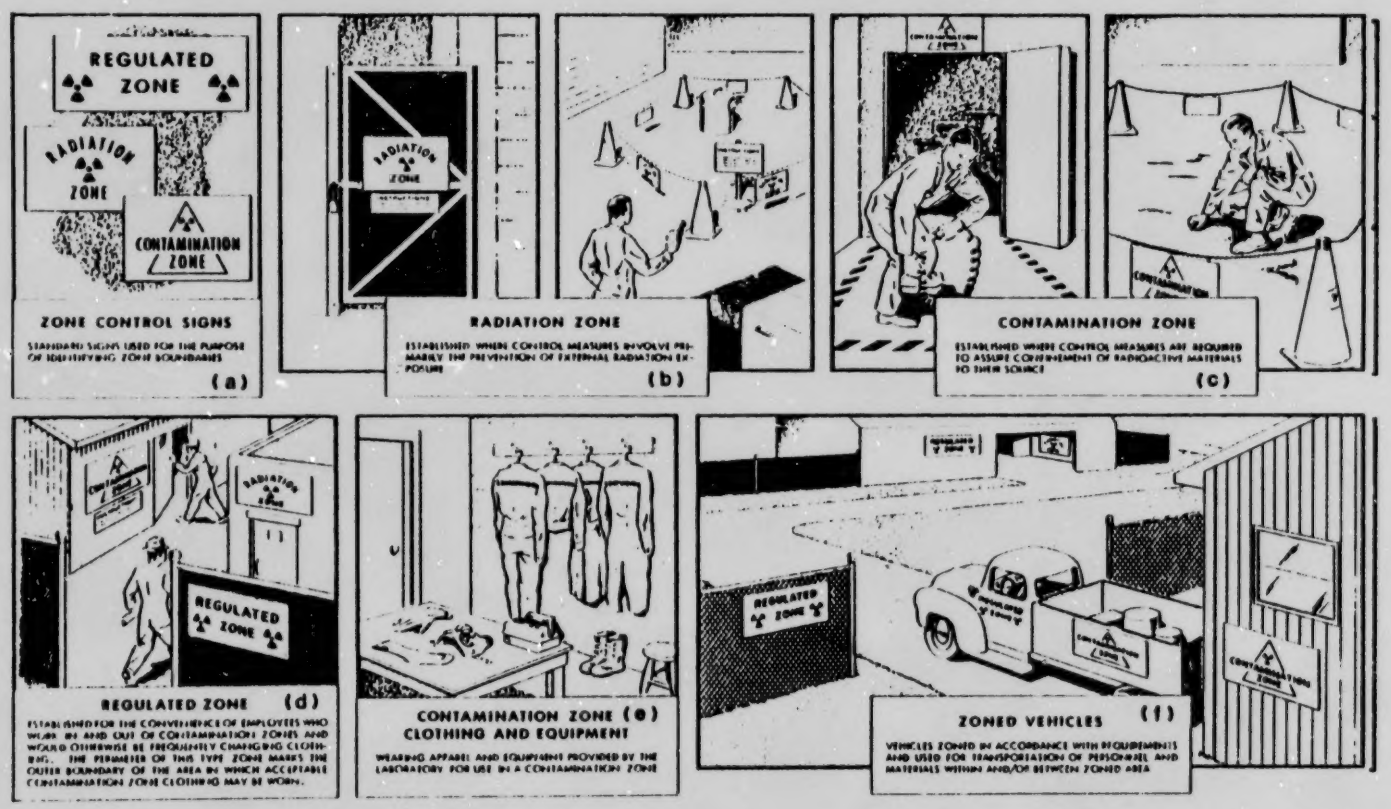


Figure 25-1-5. Zoned areas for radiation hazard and exposure control.

Minimum requirements for glove box operations are a badge, two personnel dosimeters, eye protection, long-sleeved contamination coveralls or lab coat (outer personal clothing must be removed), rubber gloves, yellow shoes or shoe covers, and plastic boots.

An area also may be designated a radiation zone (Figure 25-1-5b) – an area in which control measures are established to prevent or to minimize external radiation exposure of personnel. (In contrast, a contamination zone is established to prevent or to minimize internal radiation exposure.) Each zone is marked by the appropriate zone control signs (Figure 25-1-5a).

PERSONNEL EXPOSURE CONTROL

Personnel exposure control is provided through use of TLD meters, personal radiation monitors that provide audible "beeps," pocket dosimeters, bioassays, surveys of work areas, and shielding. Film badges are worn by all persons in the laboratory and are checked for personnel exposure levels every few weeks. The film badge must be worn at all times and should be worn face out and above the beltline.

Pocket dosimeters and audible radiation monitors should be carried by all persons in known exposure areas. Audible radiation monitors are designed to provide immediate warning of dangerous radiation levels and to measure day-to-day gamma exposure.

Bioassays such as urinalysis are performed as a check on the radionuclides taken into the body. Analyses also

may be made of sputum, feces, blood, or tissue. Health Physics officials should be notified when inhalation, ingestion, or contamination of a wound is suspected in order that a bioassay may be performed. Bioassays are performed routinely and as circumstances warrant.

Personnel exposure control also is provided by use of various other radiation-detection instruments and processes. Fixed and portable surveying and monitoring instruments monitor the radiation background of the laboratory. The environment of the laboratory building also is monitored routinely for penetrating radiation and for transferable and fixed contamination.

Because glove boxes so often are used for operations with alpha-emitting materials, two detectors of special importance are the alpha proportional counter and the continuous alpha-particulate air monitor. Glove box operations should not be performed unless these detectors are operating properly. The air monitors signal when a release occurs. Evacuation follows, and re-entry is allowed only when the proper protective equipment is worn.

Other dectectors in use include the Cutie Pie, various survey meters, scintillation and proportional counters, and hand and foot monitors. The hand and foot monitor provides low-level simultaneous detection of β and γ contamination of hands and shoes. It will not detect α radiation. Other important instruments provide neutron counting.

NUCLEAR CRITICALITY SAFETY

When a sufficient mass of certain fissionable materials is assembled in such a shape that more neutrons are being

produced by fission than can escape from the surface of the mass, the mass is said to have "gone critical": and a powerful burst of neutrons, gamma radiation, and scattered fission products occurs almost immediately. To prevent this situation and the resultant nuclear criticality accident, every laboratory that handles fissile material must set up procedures and safeguards that will prevent the material from reaching a critical mass. (A detailed discussion of nuclear criticality safety is found in Module 24-4, "Nuclear Criticality.")

PRELIMINARY PROCEDURES FOR GLOVE BOX OPERATIONS

Glove box operations are monitored carefully. Although procedures vary from plant to plant, a brief outline of some of the requirements that must be met before a glove-box operation at a typical radiochemical plant can be begun will show the scope of requirements that must be complied with for a relatively simple operation. The operation involves the transfer of three grams of plutonium trichloride from laboratory "A" into a glove box in laboratory "B." Once inside the glove box, the plutonium trichloride will be dissolved into 100 ml of water.

Before glove box operations are begun, the following forms and procedures must be completed.

- Complete a Nuclear Safety Review Request. This request will be filled out by laboratory personnel and approved by a Criticality Review Committee. The form usually is not filled out for each specific operation. The form lists the amount of fissile material in a given area. (Figure 25-1-6).

REQUEST FOR NUCLEAR SAFETY REVIEW

This request covers operations with fissile material in a control area and/or fissile material transfers that originate within the control area. The control area supervisor shall complete the blocks below and describe the process and/or operations to be performed, emphasizing the provisions for nuclear criticality safety on the reverse side of this page. This request shall be approved by the Radiation Control Officers of the originating Division and the Division(s) to which fissile material will be transferred.

EXPIRATION DATE

TITLE, CONTROL AREA, AND SUMMARY OF BASIC CONTROL PARAMETERS

(To be completed by the Control Area Supervisor)

TITLE (FOR REFERENCE PURPOSES)			DATE OF REQUEST	DATE REVIEW REQUIRED
CONTROL AREA	CODE NO.	BUILDING ROOM	DIVISION	

TYPE AND FORM OF MATERIAL	
ISOTOPIC ENRICHMENT (Wt. %)	
QUANTITY OF FISSILE ISOTOPES — PER ISOLATED BATCH OR UNIT	
QUANTITY OF FISSILE ISOTOPES — TOTAL IN CONTROL AREA	
QUANTITY OF FISSILE ISOTOPES — TOTAL TO BE PROCESSED	
Concentration or Density of Fissile Material	
Spacing of Fissile Units	
Proximity and Type of Neutron Reflectors or Adjacent Fissile Material	
Limit on Moderation	
Limit on Neutron Absorbers	
Limit on Volume or Dimensions of Containers	

THIS REQUEST MODIFIES REPLACES NSR(S) NO.

RECOMMENDATIONS

(To be completed by the Criticality Committee)

This endorsement is based on our present understanding of the operation (whether acquired verbally or in writing) and is subject to review and cancellation.

CHAIRMAN, CRITICALITY COMMITTEE — DATE

Figure 25-1-6. Request for nuclear safety review (NSR).

- After the Nuclear Safety Review (NSR) form is completed and approved and the Problem Safety Summary is approved, a letter requesting a review of the summary is sent to a Radioactive Operations Committee. Written approval by the committee is required.
- An accountability form must be completed to document transfer of the material.
- A log sheet must be completed to update the lab's inventory of plutonium.
- A label that states the amount of plutonium in the box must be posted on the box.

Glove box operations then may begin.

INTRODUCTION TO GLOVE BOX OPERATIONS

Actual operation of a glove box is simple because there are no complicated mechanical controls. The operator, properly dressed, merely places his or her hands inside the gloves and performs whatever operations are needed. In a way, however, this seeming simplicity and ease of operation is misleading. The operator may begin to take the box for granted and, although highly radiotoxic materials are being handled, conduct operations with an unconscious nonchalance that can require medical treatment.

The first principle of glove box operations is safety. The fist step to safety is an awareness of, and respect for, the toxicity of the materials that the operator handles. Operations at all time should be conducted carefully, methodically, and thoughtfully.

DRESS

Proper dress for glove box operation includes:

- Badge, personnel radiation monitor, and two personnel dosimeters.
- Eye protection.
- Long-sleeve contamination coveralls or lab coat. (Outer personal clothing is removed before coveralls are put on.)
- Rubber gloves.
- Safety shoes, shoe covers, and plastic boots.

Gloves boxes are located in limited-access zones. Any other special requirements will be posted at the entrance.

GLOVE BOX SAFETY

Safe glove box operation is largely a matter of common sense. Rules given below are based mostly upon experience and must be followed. Someone may have learned them the hard way.

1. Use common sense and good judgment. If an accident happens, don't panic; follow procedures.
2. Keep glove box and surrounding area clean and free of extraneous material.
3. Notify health physics personnel immediately if a flesh wound is received during operations.
4. Always dress properly.
5. Never operate glove box unless alarms are working.
6. Notify supervisors if any unusual condition is noticed.
7. Use special techniques to remove glass and liquids from glove box.

- Do not bag out glassware in plastic (exception – small glass bottles). Glassware should be disposed into a metal container in the glove box.
- Do not bag out pointed or sharp items in plastic (knives, spatulas, scissors, etc.). Such items should be placed into a metal container in the glove box.
- Tape (or wrap in plastic) glass items before breaking them in the glove box – be extra careful. If possible, break the contained glass inside a metal container in the glove box.
- Chips of glass on the glove box floor should be taken up by tape and disposed in a metal container in the glove box. Do not use glove fingers because they can be punctured quite easily.
- Solutions should be bagged out in pastic bottles. Do not bag out solutions in glass bottles (exception – small sample bottles).
- Metal items (such as metal waste containers) should be wrapped in plastic before they are bagged out.

7. Dispose of waste properly.
8. Check glove box gloves and O-rings for cracks, tears, and holes before glove box operations are begun.
9. Check the Magnahelic gage reading: make sure that the negative glove box pressure to the laboratory room is correct. When in doubt, contact the supervisor.
10. Obtain all necessary permits, and prepare proper paperwork before beginning glove box operations. (Some of the necessary paperwork was detailed earlier in this module.)

11. Always monitor hands after they are removed from glove box gloves.
12. Call for assistance if glove ruptures, and follow special procedures (requires training).

PLACEMENT OF MATERIALS INSIDE THE GLOVE BOX

Materials can be placed inside the glove box through the spinchter valve or through an access port by use of an air lock.

The sphincter valve is utilized only to transfer material into a glove box. It is never used to transfer material out of a contaminated box. Materials are enclosed in cylindrical cartons of which the diameter is less than the diameter of the sphincter and are pushed inside the valve. Figure 25-1-7 illustrates a carton extending into a glove box from a sphincter valve.

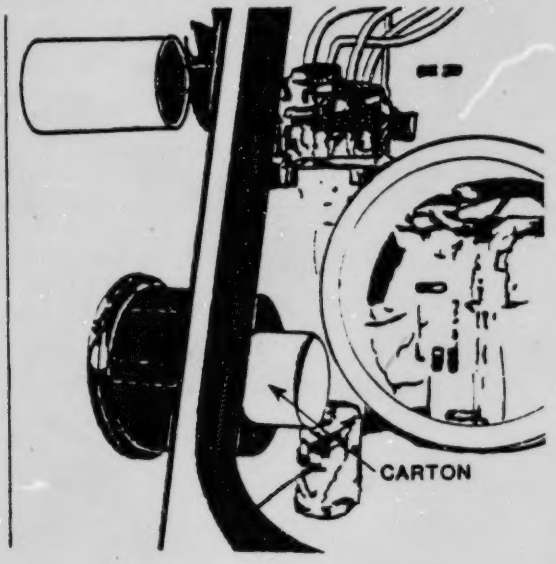


Figure 25-1-7. Carton extending into glove box from sphincter valve.

An air lock is another quick and easy way to transfer materials into a glove box. Again, material never is transferred out of a contaminated box through an air lock. Figrure 25-1-8 depicts an air lock that is essentially a stainless steel box equipped with two doors. The procedure is simple.

- Open door A; transfer material into air lock B. Before door A is opened, make sure door C is closed.
- Close door A; open door C and carefully transfer the items into the glove box. Close door C.

Air locks easily are contaminated and are not used where glove box operations include a high level of radioactivity.

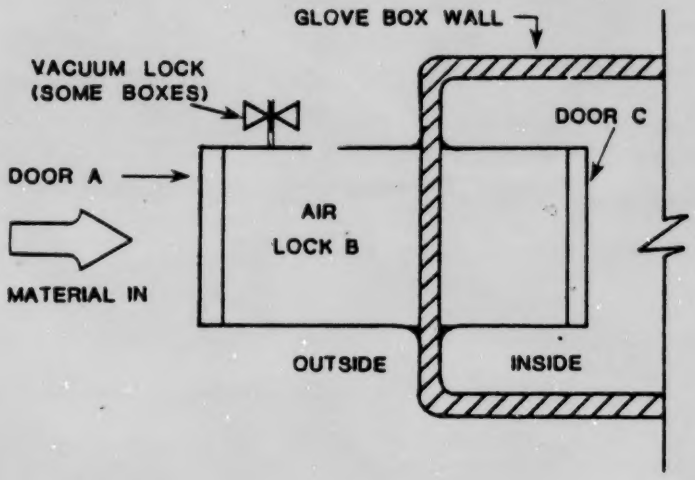


Figure 25-1-8. Glove box section showing air lock.

BAGGING IN AND BAGGING OUT PROCEDURES

Technicians remove material from a contaminated glove box by placing it into a plastic bag, "heat sealing" the bag, and removing it through an access port. This procedure is called "bagging out." "Bagging in" is the procedure used to insert a new bag into the glove box. At least two persons should be present during bagging out procedures.

Such plastic-pouch transfer techniques have permitted transfers into, and out of, highly active Research Laboratory boxes without spread of activity. Refer to Figure 25-1-9 for a typical plastic-pouch technique.

A vacuum lock is located between the inert-atmosphere boxes and an air box. Pouches are attached to the vacuum lock and the air box in order that objects introduced through either pouch can be freed of air and moisture by evacuation before they are introduced.

The pouch port is covered with a gastight door to prevent damage to the pouch and to minimize air and moisture diffusion into the inert-gas system.

These transfer methods often are utilized in a fuel fabrication facility. One modification is the large (48" diameter or larger) transfer port that has been designed into the bottom of a glove box to allow the removal of large, heavy objects. The extended pouch in this case is completely housed by a ventilated hood to ensure safety during the dielectric sealing operation.

The Procedures section of this module clarifies the steps involved in bagging in and bagging out.

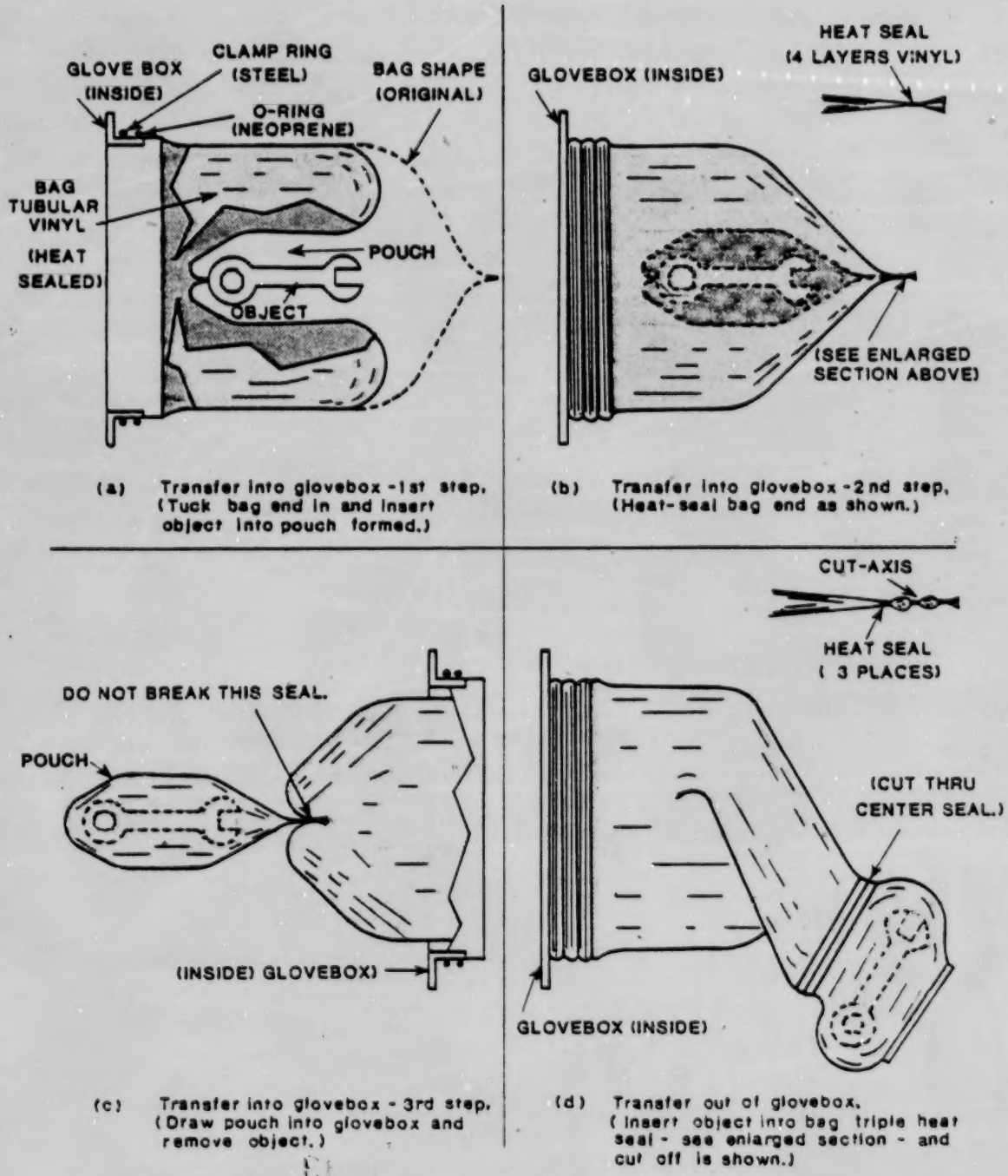

GLOVE BOX (INSIDE)
CLAMP RING (STEEL)
BAG SHAPE (ORIGINAL)
O-RING (NEOPRENE)
BAG TUBULAR VINYL (HEAT SEALED)
POUCH
OBJECT
(a) Transfer into glovebox - 1st step. (Tuck bag end in and insert object into pouch formed.)
HEAT SEAL (4 LAYERS VINYL)
GLOVEBOX (INSIDE)
(SEE ENLARGED SECTION ABOVE)
(b) Transfer into glovebox - 2nd step. (Heat-seal bag end as shown.)
DO NOT BREAK THIS SEAL.
POUCH
(INSIDE) GLOVEBOX)
(c) Transfer into glovebox - 3rd step. (Draw pouch into glovebox and remove object.)
CUT-AXIS
HEAT SEAL (3 PLACES)
(CUT THRU CENTER SEAL.)
GLOVEBOX (INSIDE)
(d) Transfer out of glovebox. (Insert object into bag triple heat seal - see enlarged section - and cut off is shown.)

Figure 25-1-9. Typical plastic-pouch technique for the transfer of objects into or out of a glove box system.

EXERCISES

1. Use Tables 25-1-2 through 25-1-5 to find the type of laboratory in which the following types of materials may be handled safely and in which of the following operations may be conducted safely.
   - Normal chemical operations with a 1-μCi quantity of ^{24}Na.
   - Very simple wet operation with an 8-μCi quantity of ^{239}Pa in solution.
   - Normal chemical operations with a 100-μCi quantity of ^{141}Ce.
   - Simple chemical operations with a 7-μCi quantity of ^{210}Bi.
2. Visit a radiochemical laboratory; list the types of glove boxes there and the operations performed within them. What are the special features of the glove boxes? How do operators qualify to operate them? Note the safety equipment in the laboratory. Are there special safety requirements necessitated by current operations?
3. List dress requirements for glove box operations.

MATERIALS

TLD.
Pocket dosimeter.
Portable survey meter.
Long-sleeve contamination coveralls.
Rubber gloves.
Eye protection.
Shoe covers and plastic boots.

Glove box with sphincter and air lock.
Plastic/polyethylene for bag out ports.
Bag sealer.
Laboratory glassware.
Metal container for glassware.
Various cylindrical cartons.

PROCEDURES

NOTE: All operations are conducted in simulated limited-access environment.

OPERATION OF THE SPHINCTER VALVE AND THE AIR LOCK

1. Dress out for operations.
2. Check glove box gloves and O-rings.
3. Check Magnahelic gage reading.
4. Place laboratory glassware into carton.
5. Loosen knob on sphincter valve; swing unit right or left past end plate.
6. Open valve by pulling down and away from end plate.
7. Push carton through opening until bottom of carton is flush with the first neoprene gasket.
8. Close and lock the door to the end plate.
9. Use glove box gloves to remove items from carton.
10. Open door of airlock. Place items (glassware) inside. Make sure that inside door is closed before opening outside door.
11. Close outside door, and open inside door. Carefully transfer items into the glove box.

"BAGGING IN"

1. Have at least two people present. Remove port cover.
2. Prepare a new bag of proper size by heat sealing one end.
3. Visually inspect the bag for defects; test the cool seal by attempting to pull the seal apart.
4. Move O-ring to inner groove.
   - Lift inner sliding port cover; let old bag expand in box.
   - Place item into the old bag or into the new one.
   - Carefully pull the old bag away from the box so that bag edge is near the inner groove.
   - Place new bag on port over the old bag, checking to be sure that bag edge does not curl under at any point. The new bag should be pushed all the way to the back of the port and folded back to the inner groove. Stretch O-ring and pull over new bag O-ring in inner groove; push new bag edge to back of port.
   - Reach through from inside of the box, and carefully pull the inner bag into the box.
   - Close inner sliding-port cover.
   - Roll O-ring to the outer O-ring groove.
   - Check for contamination. Replace port cover.
5. If there are two O-rings on the port, remove the outer O-ring. When bagging operation is completed, place the O-ring into the outer groove and check for contamination.

"BAGGING OUT"

1. Have at least two people present.
2. Remove bag port cover.
3. Inspect old bag to determine if it is long enough to hold the item coming out and still leave enough slack for a good heat seal.
4. If bag is not long enough, replace it as described under "Bagging In."
5. Place item into the bag and support it while bringing the heat sealer into position.
6. Remove as much air as possible from the bag.
7. Position heat sealer so that the bag will lie flat across it with no wrinkles. Leave enough slack between sealer and box so that there is no pull on the seal.
8. Support item in the bag so that it does not pull on the new seal; heat seal the bag.
9. With scissors, cut in the middle of the heat seal. Check for contamination.
10. Replace bag port cover.
11. Materials containing high radiation gamma emitters should be monitored by a Health Physics representative before removal from a glove box.

DATA TABLE

None.

REFERENCE MATERIALS

Barnwell Nuclear Fuels Plant. A Guide to Good Practices at Plutonium Facilities. Publication #2086.

Friedlander, G.; Kennedy, Joseph W.; and Miller, Julian M. Nuclear and Radiochemistry. 2nd ed. New York: John Wiley and Sons, 1964.

Wang, C.H.; Willis, D.L.; and Loveland, W.D. Radiotracer Methodology in the Biological, Environmental and Physical Sciences. Englewood Cliffs, NJ: Prentice-Hall, 1975.

SECTION I: MULTIPLE CHOICE

Choose the best response(s) to the following questions:

1. A glove box used to handle alpha-emitting material is maintained –
   a. At a slightly negative pressure.
   b. At a pressure equal to the laboratory atmosphere.
   c. At a slightly positive pressure.
   d. With an inert atmosphere at a slightly negative pressure.

2. The sphincter valve is used to –
   a. Transfer material into and out of the glove box.
   b. Transfer material out of the glove box only.
   c. Equalize glove box and laboratory pressure.
   d. Transfer material into the glove box, never out of it.

3. One disadvantage of an air lock is –
   a. The difficulty and complexity of operation.
   b. Its tendency to become contaminated.
   c. Its relatively great expense.
   d. The impossibilty of transferring liquids through it.

4. Some factors that may increase or decrease the degree of hazard in the handling of radioisotopes are –
   a. Physical form of the isotope.
   b. Complexity of the laboratory procedures.
   c. Type of equipment used to handle the material.
   d. Type of laboratory in which the operations are conducted.

5. A potentially contaminated area in which low levels of radioactive material are permitted is –
   a. A limited-access zone.
   b. A radiation zone.
   c. A regulated zone.
   d. A contamination zone.

6. The hand and foot monitor –
   a. Provdes detection of gamma radiation only.
   b. Provides detection of alpha, beta, and gamma radiation.
   c. Cannot detect gamma radiation.
   d. Cannot detect alpha radiation.

7. Pointed or sharp items and glassware –
   a. Should be removed through the sphincter valve.
   b. Should be removed through the air lock.
   c. Should be taped inside a polyethylene bag and bagged out.
   d. Should be bagged out inside a metal container.

8. The NSR form must be filled out –
   a. For highly radioactive materials only.
   b. For all nuclear material.
   c. For all fissile material.
   d. For class I and II nuclear materials.

9. Bioassays are conducted –
   a. At specified intervals only.
   b. After an accident has occurred.
   c. Routinely and at need.
   d. Seldom due to the inordinate expense.

10. Inert atmospheres are required –
    a. For all fissile material.
    b. For pyrophoric materials.
    c. For class I radionuclides.
    d. For class I and II radionuclides.

SECTION II: ESSAY

11. Describe design and safety features of a typical glove box, emphasizing the features designed to prevent contamination. Include safety features of the window design, glove and port closures, exhaust system, pressure and flow control systems, and fire and electrical safeguard systems.

12. Define and describe the following terms:

- Clean zone.
- Regulated zone.
- Contamination zone.
- Limited-access zone.
- Radiation zone.

State the purpose of formal laboratory zoning.

13. Describe equipment and procedures used for personnel exposure control, including –

- Film badges.
- Pocket dosimeters.
- Bioassays.
- Alpha counters and monitors.
- Hand and foot monitors.

14. Describe typical preliminary procedures for a glove box operation with fissile materials.

15. List and describe general glove box safety rules.

16. Given: Normal chemical operations with a 0.5-μCi. quantity of ^{239}Pu.

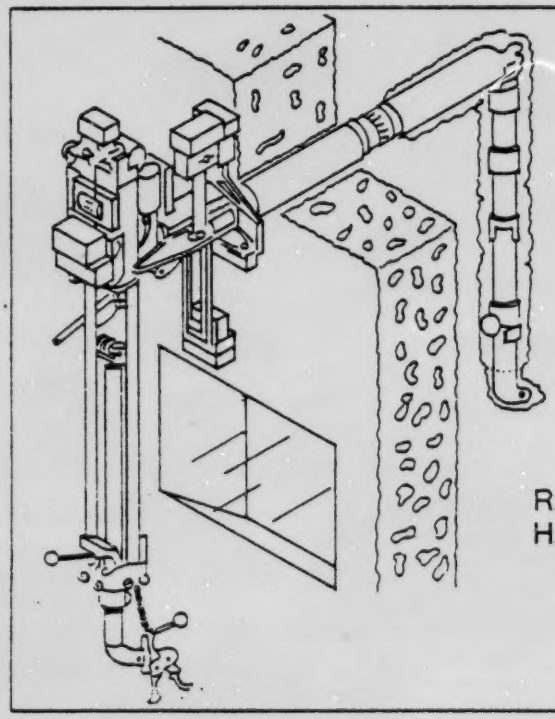
Find: The type of laboratory in which this material may be handled safely. Use Tables 25-1-2 through 25-1-5.

Solution:

NUCLEAR TECHNOLOGY

MODULE 25-2

GLOVE BOX OPERATIONS - ADVANCED



RADIOACTIVE MATERIAL
HANDLING TECHNIQUES

COURSE 25

ORD
CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

The safe handling of toxic and radioactive materials requires that operating personnel be enclosed or that the hazardous material be enclosed. Enclosure of the operator would require very cumbersome apparel and would result in a much-reduced working efficiency. When the enclosure of the hazard is feasible, the operator can work under more nearly normal working conditions. Glove boxes are used to handle radioactive materials that in some cases are also toxic and pyrophoric.

The procedures carried out in glove boxes are very diverse and call for facility-specific design. Operations performed in glove boxes include wet and dry chemistry, metallurgy, nuclear fuel fabrication, and fuel preparation. Metallurgical work can include such activities as melting and casting, machining, rolling, and pelleting, and heat treatment. The glove box acts as a containment of the contamination that would result if the material were handled in normal industrial settings. It also provides shielding against radiations with low penetrating power and some protection against more highly penetrating radiations.

This module describes a few representative processes carried out in glove box facilities. The types and forms of radioactive materials handled in glove boxes are briefly described. General considerations used in the design of glove box facilities, such as the structural materials, the protective coatings, the window materials, the glove materials, the auxiliary equipment, and the ventilation requirements also are discussed. Safety practices as they relate to all facilities are discussed. The industrial safety considerations of glove boxes are enumerated, and the process hazards of fire and explosion are discussed thoroughly in this module. Glove-changing procedures also are included.

MODULE PREREQUISITES

The student should have completed Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; Course 23, "Nuclear Chemical Processes"; and Module 25-1, "Glove Box Operations – Fundamentals."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Identify the two types of common hazards capable of spreading contamination when pyrophoric materials are handled in glove boxes.
2. Describe the basic functions of the glove box with respect to safety.
3. Explain how glove box criticality can be prevented and how it can be controlled.
4. Identify the most effective long-term glove box structural materials and the best window materials.
5. Discuss the type of gloves that should be utilized with a glove box when either maximum sensitivity of touch or maximum protection from alpha or beta radiations is required.
6. Describe several industrial safety precautions necessary when glove boxes are in use.
7. Explain how a puncture glove is replaced.
8. Discuss glove box metallurgical operations.
9. Identify types of radioactive materials that can be processed in glove boxes without the use of extra shielding.

10. Correctly explain special features and safety procedures required when aqueous solutions of plutonium are processed within a glove box.
11. Elaborate upon the fire and explosion hazards, as well as their prevention and control, when pyrophoric substances are manipulated in a glove box.

PROCESSES PERFORMED IN GLOVE BOX ENVIRONMENTS

Glove boxes are used throughout the nuclear industry for the handling and processing of nuclear or radioactive materials. As a result of the diversity of research and industrial processes in which they are used, the design and construction may vary widely from facility to facility. Glove boxes can be used to perform operations in a controlled environment, either for the benefit of the operator or of the operation. The welding and casting of highly reactive metals, such as titanium, and the handling of materials, such as lithium, that require a very dry atmosphere are examples of glove box use for the benefit of the operation. On the other hand, and more frequently in the nuclear-related industries, glove boxes are used to protect the operator and property from contamination with radioactive and toxic materials. A brief description of some of the uses of glove boxes in research and industrial applications follows.

ENCAPSULATION OF RADIOACTIVE SOURCES

A procedure in which glove boxes prove very useful is the encapsulation of sources that exhibit mildly penetrating radiations such as beta and alpha particles. A specific example is the encapsulation of a 65-W promethium sesquioxide heat source. Promethium-147 heat-source capsules were fabricated for the Air Force for use in a thermal preconditioning unit within an advanced aircraft. Promethium met the requirements for this source: It afforded a low external dose rate after encapsulation since it was a beta emitter and had an appropriate half-life, an adequate power density, and

adequate availability. The sources were encapsulated in tantalum. Figure 25-2-1 illustrates the promethium heat source after encapsulation. In Figure 25-2-2, the fabrication facility of the promethium source is depicted. As is readily apparent, the whole source fabrication was carried out in a series of glove boxes, each having different process purposes.

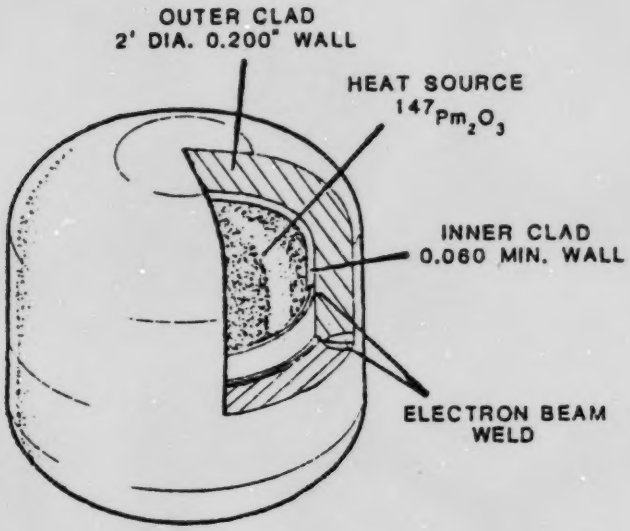


Figure 25-2-1.
Promethium oxide
heat source.

The promethium fuel material first was assayed as to purity of Pm-147; then an oxalate precipitation and an oxide conversion procedure were performed on the material. A calcination procedure was carried out at 1100°C. A powder then was made of the product from the calcination step. The powder was weighed, pressed, and sintered. The pressing was performed under 150,000 psi and the sintering at about 1350°C. The inner capsule was then placed around the source and welded, with an electron-beam welder. The welds were examined. The outer assembly was added and welded, with

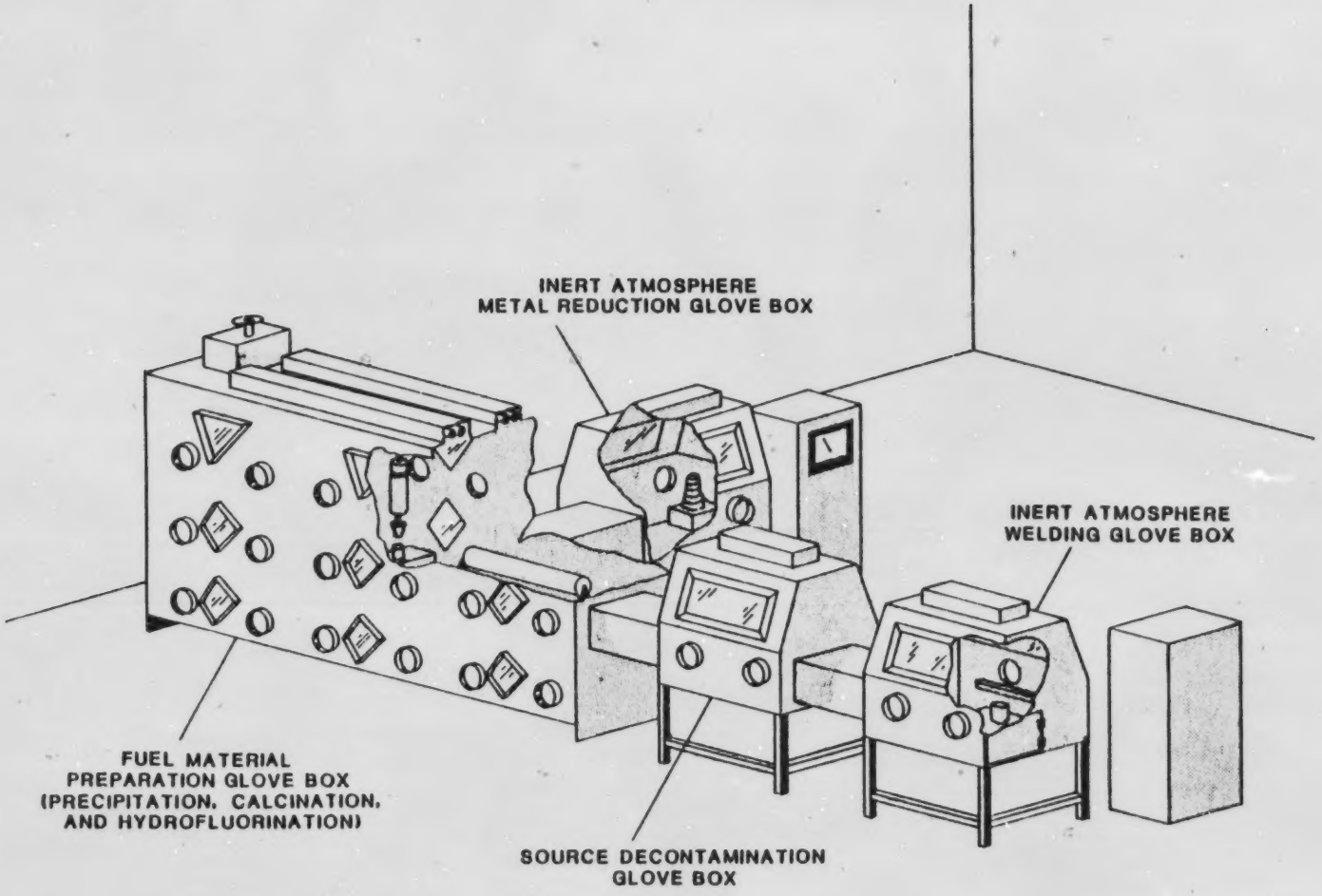


Figure 25-2-2. Promethium source fabrication facility.

the electronic-beam welder. The source encapsulation procedure points to the variety of operations that can be performed in a glove-box system.

GLOVE BOXES IN THE HANDLING OF TRANSURANIC ELEMENTS

The use in research and fuel fabrication of glove boxes demonstrates their usefulness in the handling of high-intensity alpha emitters, which also may be pyrophoric and gamma active. Among the laboratories at which research with transuranic elements is performed are the Oak Ridge National Laboratory, Transuranium Research Laboratory and the Institute for Transuranium Elements at Karlsruhe (Federal Republic of Germany). Some features of the Karlsruhe facility will be described here.

At Karlsruhe, about 600 glove boxes are used. About 80% of those are employed in the handling of 100 grams to 1-kilogram amounts of ^{239}Pu. A small portion of the glove boxes are used with additional shielding in the form of lead sheets or lead glass for work with recycled plutonium. Gram amounts of ^{241}Am also have been handled in glove boxes; for example, with tongs and additional shielding to prepare Al-Am targets for experimentation. Gamma-ray dose measurements with americium have shown that gram amounts lead to a high irradiation dose for the operators; consequently, direct hand contact in the glove boxes is avoided.

Of interest at this facility are the precautions taken to prevent criticality accidents when ^{239}Pu or ^{235}U are handled. Working areas have been divided into two types of working zones in which limited amounts of fissile materials are allowed. One area consists of "wet" laboratories in

which a maximum of 225 grams of fissile material is allowed. The other area is a "dry" area in which work can be performed with up to 2.5 kg of fissile material. Certain types of equipment, such as water-cooled furnaces, are permitted in the dry areas only if it can be ensured that the hydrogen-containing liquids that leak will not lead to a criticality accident. This is achieved by the limiting of these liquids to amounts that ensure that a safe geometry is maintained.

OTHER GLOVE BOX PROCESSES

Glove box design is influenced by the toxicity, form, and quantity of radioactive materials to be handled; by the type of operations; and by the economics of the process. A glove box used in plutonium metallurgy is illustrated in Figure 25-2-3, which shows the complexity of glove boxes for many procedures. Equipment components such as vacuum pumps, lights, motors, drives and controls usually are located outside the glove box. Careful attention should be paid to sealing of glove box openings. For fuel fabrication processes, the rolls, roll housing, and wobblers are the only parts of a rolling mill that extend into the glove boxes. Rotating shafts pass through the glove box walls into bearing seals, or through O-ring grease seals. Leakage of contaminants occurs when alignment or surface finishes become defective.

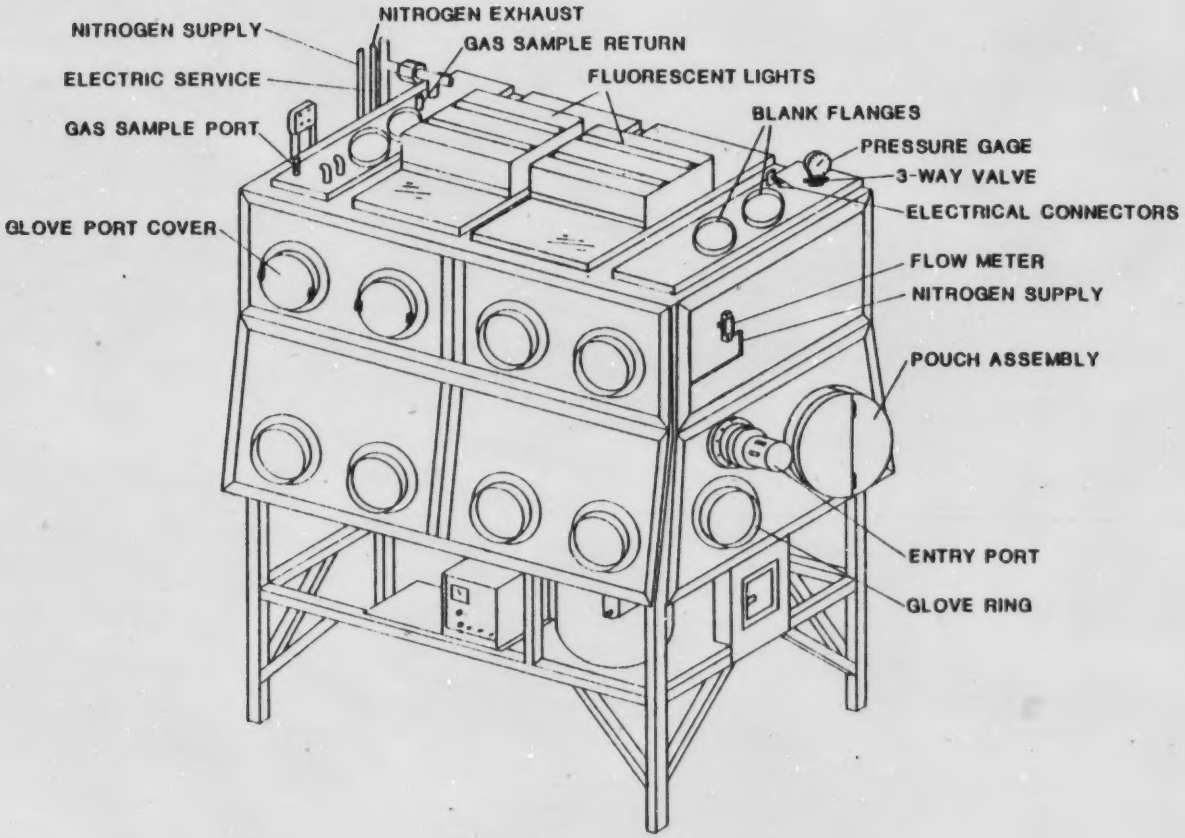


Figure 25-2-3. Plutonium metallurgy research glove box, large size, showing service connections.

RADIOACTIVE MATERIALS

Glove boxes are used in power processes and in wet chemistry. For use with solutions, glove boxes provide a containment for inadvertent spills of the radioactive solutions. In laboratories in which glove boxes are used to transfer radioactive solutions, the glove box liners often are paper for ease in decontamination. Specific uses of solutions in glove boxes include the transfer of solutions upon which neutron activation analysis is being performed. Such samples may undergo radiochemical separations to eliminate gamma peaks that would interfere with sample counting.

A survey of glove box uses would indicate that their principal use is in the handling of transuranic elements that have high alpha activities. In the fabrication of samples of these elements or of reactor fuel, wet chemistry may be done on the samples. But eventually, at some point in the process, the sample is in a powder form. In such a case, the glove box serves as the minimal shielding needed to stop the alpha particles, as well as a barrier to the spread of contamination by particulate dispersion.

With regard to the handling of large quantities of plutonium in glove boxes, concern for criticality is necessary, especially if it is in solution. If handled in a hydrogenous medium (i.e., in a moderated form), only very small amounts of plutonium can be present. In the case of unmoderated portions, consideration still must be given to criticality; but larger amounts may be handled.

Prevention of criticality is achieved through the control of mass and geometrical shapes. In laboratories, the amounts of fissile material in both wet and dry sections

are limited in order to reduce the criticality problem. An important aspect in the prevention of accidental criticality is the practice of making certain that the substances never are handled in minimum critical mass geometries and quantities. The exact amounts of fissile material that can be handled, and the allowed geometrical shapes and dimensions in the processes, are ultimately determined by the form of the compound being processed.

GENERAL DESIGN CONSIDERATIONS

Since glove boxes are used in a variety of processes, the design of process-specific boxes may differ vastly. However, several considerations must be used for all boxes. The process being performed dictates the size and shape of the enclosure, the construction materials, the air-flow patterns, ventilation equipment, filter selection, atmosphere controls, lighting, glove and transfer port size and location, window size, window construction and location, the preparation requirements for piping, etc.

GLOVE BOX STRUCTURAL MATERIALS

Glove box designers and users may choose their own designs based upon estimates of hazards, operational requirements, and their knowledge of available materials. Glove box structural materials should be resistant to chemical action and should be noncumbustible, resistant to heat, resistant to shock, resistant to surface abrasion, nonabsorbent, easily decontaminated, and mechanically strong. In

addition, they should be resistant to permanent distortion and to radiation damage. Stainless steel is the most common structural material. It is particularly suitable for long-term applications. Mild steel, aluminum, plywood, and glass-fiber-reinforced plastics also have been used as construction materials for glove boxes.

Table 25-2-1 rates the structural materials for properties of interest in glove-box operations. Stainless steel is recommended in general because of its high fire and corrosion resistance. Aluminum is recommended as a less expensive choice. The use of stainless steel is disadvantageous if hydrofluoric, hydrobromic, hydrochloric acids, halogen salts, or sulfuric acid is placed into the box.

TABLE 25-2-1.
RATING OF GLOVE BOX STRUCTURAL MATERIAL.

	Stainless Steel	Mild Steel	Aluminum	Plywood	Reinforced Plastics
Corrosion resistance	Good	Poor	Good	Poor	Exc.
Combustibility	None	None	None	Poor	Fair
Heat resistance	Good	Good	Fair	Poor	Fair
Abrasion resistance	Exc.	Good	Fair	Poor	Fair
Decontamination	Exc.	Poor	Good	Fair	Exc.
Strength	Exc.	Exc.	Good	Fair	Good
Workability	Fair	Good	Good	Exc.	Good
Cost	High	Medium	High	Low	Medium

Aluminum also is attacked by the halogens and halogen salts; by most other salts, inorganic acids, and hydroxides; and by copper, silver, lead, and nickel compounds. Smooth, polished surfaces are recommended to facilitate cleaning and decontamination as well as to avoid localized corrosion from trapped moisture and condensates.

PROTECTIVE COATINGS

The interior surfaces of glove boxes must be coated in some applications to produce corrosion protection, to provide an easier surface to decontaminate, and to improve the retention of transparency. Removable coatings often are utilized to facilitate decontamination and adsorption of contaminants. Additional corrosion protection also has been achieved from phenolic coatings.

WINDOWS

The operation proposed for the glove box governs, to a degree, the choice of window material. No single material is suitable for all glove box operations. Some desirable properties of window materials are satisfactory optical quality, heat resistance, noncombustibility, resistance to explosions, resistance to chemical attacks, production of little smoke when burning, good resistance to radiation damage, and resistance to impact. In addition, the windows should be flexible, easily machined for replacement or modifications, and available in standard sizes and thicknesses. The prime reason for the window is to provide an adequate

view of the glove box interior. The window size should be restricted to a minimal size (consistent with visibility requirements) due to safety constraints. The ratings of the various choices for window materials are listed in Table 25-2-2. Wired glass is strongly recommended, in general, if visibility allows. Otherwise, laminated safety glass is recommended. When hydrofluoric acid exposure is serious, a polycarbonate such as Lexan is recommended.

TABLE 25-2-2.
EVALUATION OF DIFFERENT WINDOW MATERIALS.

	Glasses			Plastics			
	Laminated	Tempered	Wired	Plex.G	Plex. SP-3	Homalite	Lexan
Optics	Exc.	Exc.	Fair	Exc.	Exc.	Exc.	Good
Combustibility	Exc.	None.	None.	Poor	Fair	Fair	Fair
Heat resistance	Fair	Good	Exc.	Fair	Fair	Fair	Fair
Impact resistance	Fair	Good	Good	Good	Good	Good	Exc.
Chemical resistance	Exc.[1]	Exc.[1]	Exc.[1]	Good	Fair	Good	Good
Radiation resistance	Exc.[2]	Exc.[2]	Exc.[2]	--	--	--	--
Abrasion resistance	Exc.	Exc.	Exc.	Fair	Fair	Good	Poor
Flexibility	Poor	Fair	Poor	Exc.	Good	Fair	Good
Workability	Poor	Poor	Poor	Exc.	Good	Good	Good
Cost	Medium	Medium	Medium	Low	Medium	High	High

[1]Except to hydrofluoric acid.

[2]If nonbrowning glass (cerium added).

GLOVE SELECTION

Gloves represent an inherent weak point in the glove box containment system. The general properties desired in glove materials are physical and mechanical soundness; flexibility; resistance to wear and tearing; resistance to water permeability; resistance to gas diffusion; chemical resistance; and resistance to heat, fire, and explosion pressures.

Neoprene is the most commonly used glove material. Hypalon also is employed. Some gloves are lead-impregnated to shield against gamma rays. Surgeon's latex gloves sometimes are worn as liners to provide a secondary defense against leakage. Various hand and sleeve arrangements are available. Thickness ranges from 0.008 to 0.055 inches. One-piece construction is preferred as a defense to the leakage of radioactive materials. Neoprene gloves are the thinnest type and are preferred for micromanipulation. Hypalon gloves are thicker but more durable and are better shields against beta particles. Use of hypalon reduces the sensitivity of the operator's touch.

Gloves usually are designed for a specific hand (right or left), but gloves suitable for either hand are commercially available. If the gloves are involved in a fire, they likely will lead to burn-through and possible clogging of the HEPA filters. Therefore, the fire resistance of the gloves is invaluable in the gaining of time during which any fire that occurs in the glove box could be controlled. In this respect, neoprene gloves tend to be self-extinguishing when the source of ignition is removed.

Since glove box work frequently involves materials that are pyrophoric, moisture sensitive, toxic and/or radio-

active, all glove materials must be semipermeable to water, solvents, and gases. Care is needed in order to select the material that will best prevent harm to the operator's hands, excessive deterioration to the gloves, and the diffusion of undesirable components of the room atmosphere into the glove box environment. The use of as thick a glove as possible is warranted because it will be more likely to resist chemical attack, to protect personnel, to reduce radiation exposure, and to prevent mechanical failure. The probability of a fire affecting the gloves can be reduced if the gloves are tied together outside the box when not in use.

UTILITIES AND AUXILIARY EQUIPMENT

Since a wide variety of processes are performed in glove boxes, equipment and component penetrations into the box vary from facility to facility. There are some recommendations to be followed in maintaining the physical integrity of the containment of the glove box. Whenever possible, auxiliary equipment should be located outside the glove box to avoid contamination and to conserve working space in the box. This approach also facilitates maintenance and repair. If electrical components must be located near combustible concentrations of materials in the box, the equipment should be of a type approved for such an environment. (Sparks from some components can ignite combustible materials.) Overhead service and utility lines may be used to minimize the spread of contaminants in the event of a spillage. This will also allow for flexibility in glove box operations.

Openings in the glove box walls should be tightly sealed. Seals should be checked regularly for deterioration and leakage. Equipment within and without the glove box should be resistant to any anticipated corrosion conditions. Check valves and in-line filters should be capable of preventing flowback. Components and equipment should be labeled, color-coded, or otherwise readily identifiable to facilitate normal operation and servicing. High-pressure lines needed in the box should be limited in size to prevent pressurization of the box in the event that they break. Precautions should be taken when coolants are needed in order that they will not rapidly generate gas when spilled and result in overpressurization of the box.

VENTILATION

Proper design of the ventilation is essential to safe glove box operations. A ventilation system should assist in the prevention of the spread of contamination from the glove box to the working area or to the adjacent parts of the building or outside atmosphere. The room ventilation should be arranged in such a manner as to force flow from zones of lower to higher contamination. This is accomplished by making the room pressure such that flow will occur in that fashion. Glove box ventilations systems consist of four basic types:

- Once-through air.
- Once-through inert atmosphere.
- Recirculation of air.
- Recirculation of inert atmosphere.

In once-through air systems, an absolute-intake air filter provides additional cleaning and prevents backflow from the box. Air then is exhausted through filters.

Inert atmosphere boxes are provided to prevent contamination of materials being handled and/or to prevent air-dependent fires and explosions. Plutonium is readily contaminated in normal air atmospheres, for example. It is pyrophoric, particularly when in finely divided form. It can ignite spontaneously at room temperatures in air that contains moisture. If moisture levels of the air are kept below 500 to 1000 ppm, the ignition hazard will be decreased. For this reason, inert atmospheres commonly are provided for the handling of plutonium. Other pyrophoric materials include uranium, thorium, and zirconium, as well as their alloys. Inert atmospheres also are needed when chemical operations are performed with flammable liquids. Argon and helium are true inert gases and usually are recirculated when used to provide an inert atmosphere. Nitrogen often is employed for once-through inert systems. In addition to safety considerations, the use of inert atmospheres in some cases can aid in holding impurities to a few ppm; for example, in the case of work with ceramic fuel mixtures.

The gas supply for inert systems should be located in an area separate from the glove box to reduce the possibility of damage to the glove box and to reduce clutter in the vicinity of the box. Indicators should be provided for prompt indication of overpressurization. Suitable emergency switches and alarms should be provided. Continuous monitoring of the inert atmosphere should be performed to detect impurities, leaks, contaminants, and abnormal heat. Duplicate arrangement of components critical to continuous operation should be made in the design. The equipment should be of such

a design as to be able to handle a power failure.

Additional criteria for safe design and operation of ventilation systems include the maintenance of a pressure gradient between areas of low-contamination risk and areas of high risk. The once-through passage of air is desirable in the building design. To aid in fire protection, the sectionalizing of glove box lines and ventilations systems is desirable. An emergency purge system is required at high-hazard glove box installations; the system must be capable of monitoring a negative pressure within the box should a breach of integrity occur. If a high degree of fire hazard exists, a means of slowing the flow in the ventilation system is desirable.

SAFETY PRACTICES

The overall safety of glove box facilities depends upon proper administration and control of operation. The planning of the safety programs is tantamount to proper control of the operation. Administration and organization of the program vary from facility to facility, but successful programs all provide for several basic functions. Some provision must be made to ensure that all the proper procedures are carried out. The anticipation of hazards dictates, to a large degree, how safe the plant operation will be. Preplanned emergency procedures are critical to ensure proper responses of personnel upon the actual occurrence of an accident. Thorough review of these plans is necessary. All operators must be trained and educated in safety procedures, and provisions must be made to ensure that the procedures will be executed.

Operating procedures must be written in order to promote safety, and even experimental procedures must be analyzed. Instructions should be originated and kept current by persons responsible for operation. The procedures should be reviewed by supervisory personnel and by appropriate hazard control groups. Emergency procedures should be kept current to allow for changes in plant layout.

STANDARD SAFETY PROCEDURES

In the use of glove boxes for the handling of radioactive materials, several general safety considerations must be followed. First, the radioactive hazards must be evaluated. Points to be evaluated include the type and quantity of radioactive materials to be handled, the appropriate assessment of the external hazards, the possible internal exposure, and the contamination that all of these represent. It is common practice to estimate the dose rates at 10 cm from the material in order that the external exposure hazard can be projected. This represents a typical handling distance for glove box manipulations. It is also convenient to extrapolate from this distance to other distances.

In the use and handling of transuranic elements, the dose rates as calculated from point sources are appropriate because samples handled are very small. Several approaches are used to evaluate biological significance of the materials, the required containment, and the potential severity of contamination release. Included in these approaches are the maximum permissible concentrations, biological intake values, and lung and body burdens. Other radio-activity-

related factors also are evaluated; these factors include heat production, increased chemical reactivity, formation of highly ozidizing ozone, and radiolysis of solutions. The technician must determine the dimensions of single spheres (particles) of material required to equal the maximum permissible lung burdens for the different nuclides with which work is being done.

Secondly, any concurrent conventional industrial safety risks encountered in the plant must be identified. Experience has shown that adverse radiation accidents have occurred even when personnel have understood and followed the appropriate radiation-protection procedures. The incidents are not caused directly by radioactivity, but result from its behavior following a concurrent industrial safety mishap such as a fire. It is essential that all normal safety hazards involved in the process be understood. Potential radioactivity risks associated with industrial safety problems should be assessed. (Such risks are discussed under the next heading.)

Thirdly, equipment should be designed; operating procedures should be developed; and the proficiency of operating personnel should be ensured to provide necessary safeguards by which operation can be performed with minimal risk and minimal constraints. Poorly planned safety procedures will result in maximum constraint being imposed upon the operation.

Fourthly, necessary safeguards should be incorporated into equipment as much as possible. In addition, proper monitoring instrumentation and surveillance must be available to detect departures from safe operation. Radiation monitoring equipment must be designed with regard to the energy dependence of the radiations to be detected, its response in mixed radiation fields, the geometrical considerations

in the process (i.e., contact with the material), and uniformity of response to the radiation.

INDUSTRIAL SAFETY CONSIDERATIONS IN GLOVE BOX OPERATIONS

A glove box places certain restrictions upon an operator that normally would not be encountered if the operation were performed in an open area. Some of these restrictions are as follows:

- Restriction of the operator's movements and position (resulting in fatigue).
- Restricted vision of the operator with respect to the operation being performed.
- Limitation placed on the operator's sense of touch by the gloves.
- Need for the operator sometimes to work in the gloves at elevated levels.
- Susceptibility of the operator's gloves to damage by puncture or burning.
- Slow speed at which the operation must be done in comparison to work done without gloves (resulting in fatigue and tension).

Glove box and equipment features should include –

- A design that allows the operator to reach all parts of the box interior with an arm-length glove.
- A window with adequate visibility and low abrasion potential.
- Lighting arranged in such a manner as to avoid glare on windows from reflected light.

- Use of platforms for working at elevated positions, including guard rails if necessary.
- Elimination of sharp edges within the glove box.
- Appropriate outside controls for emergency shutoffs and equipment.

Among industrial safety recommendations that apply to the room and operator are the following:

- Issue and maintenance of comfortable protective clothing.
- Avoidance of cluttered work and flow areas.
- Adequate ventilation of the room to eliminate irritating fumes.
- Adequate exit facilities.
- Nonslip floors that are chemical resistant and easily decontaminated.
- Properly labeled chemicals and solvents.
- From an operating viewpoint, avoidance of a prolonged, continuous work period.

PROCESS HAZARDS

As previously mentioned, one of the prime uses of glove boxes is in the handling of transuranic metals. These materials are pyrophoric and have a high alpha activity. Of great concern at transuranic facilities are the explosion and fire hazards associated with these materials. Many glove box components are combustible; for example, rubber gloves, plastic pouches, and plastic windows. A glove box is then vulnerable to involvement in a fire which could

lead to loss of containment integrity. A fire or explosion could lead to an overpressurization of the box and cause its components to fail. Filters in the ventilation system also are susceptible to fire or explosion damage. The control and extinguishing of fires in glove boxes is complicated because the box is enclosed and because the extinguishing agent must be applied without overpressurization of the box. Overpressurization is important since the glove box may not be leaktight – or it actually may blow apart – under the pressure.

Where plutonium or uranium is being used, special care must be exercised to avoid the introduction of extinguishing agents, such as water, that could act as moderators and lead to criticality. The extinguishing agent also must not be adversely reactive with the contents of the box. A glove box fire that generates smoke and soot can clog the filters and cause the pressure in the glove box to become positive; therefore, the extinguishing process must be performed quickly.

Explosions in glove boxes easily can breach the containment by blowing out gloves, pouches, and windows. If explosions occur in the exhaust system, filters may fail, allowing the radioactive contamination to be dispersed directly into the atmosphere. In the use of glove boxes, all the possible sources of explosions and fires must be considered. Between 1956 and 1965, twenty-four fires and nineteen explosions at glove box facilities were reported. The longest-lasting fire was 12 minutes. All of these incidents led to significant contamination outside the box. Plutonium fires were the principal ones in glove boxes. The loss of containment was due to the burnout of combustible glove box components and the failure of such components to withstand

pressures developed by the explosions and flash fires.

Since the rapidity with which the fires are extinguished is important in the prevention of contamination spreading, fire detectors are included in the glove boxes in facilities at which fires are possible. Quick and effective control of any fire is necessary to prevent loss of containment. Tests have shown that gloves may fail within 20 to 30 seconds if exposed to fire. A large variety of extinguishing agents and application methods are available for extinguishing glove box fires. Water, foam, dry chemical, halogen agents, and high-expansion foams are suitable for the extinguishing of fires in the boxes. A comparison of extinguishing agents is provided in Table 25-2-3.

The suppression of explosions depends upon detection of combustion in its earliest stage and the prevention of further growth of pressure in the glove box. Detectors in explosion suppression systems operate by detection of pressures, temperature, or radiation. A detector generates a signal to an amplifier, which discharges a capacitor through suppressor units. At the suppressor, a small blasting cap operates to start the rapid discharge of the suppressant. The suppressant normally is a halogenated fluorocarbon. The rapid discharge permits high extinguishing capability. Dishcarge speeds of up to 600 feet per second are achievable in the suppression of explosions. Other explosion-protection factors in the system take action in addition to suppression. Among those are explosion venting by burst discs, advance suppression or inertion further downstream in equipment to prevent chain explosions, shutdown of equipment, and the sounding of alarms. An explosion suppression system in a glove box would allow the box to withstand the maximum pressure pulse expected from a suppressed explosion. These

systems are not recommended for protection against non-air-dependent fires and explosions.

TABLE 25-2-3.
COMPARISON OF EXTINGUISHING AGENTS.

	Water	CO_2	Dry Chemical		High-Exp. Foam	Halon 1301	Dry Compound
			Ordinary	Multi-Purpose			
Suitability for: CLASS A (Ordinary combustibles)	Yes	No (some surface fires)	No (some surface fires)	Yes	Yes	Yes	--
CLASS B (Flammable liquids)	No (unless flash-point over 150°F)	Yes	Yes	Yes	Yes	Yes	--
CLASS C (Electrical)	No	Yes	Yes	Yes	Yes	Yes	--
CLASS D (Metals)	No	No	No	No	No	No	Yes
CRITICALITY HAZARD	Yes	No	No		Negligible	No	No
CONTAMINATION SPREAD HAZARD	High	Moderate	Low		Low	Low	Low
PRESSURIZATION	No	Yes	No		Possible	Unlikely	No
FILTER CLOGGING	Temporary partial clogging	Possible	Permanent partial clogging		Temporary partial clogging	None	--
DAMAGE	Possible	None	To electrical parts; general cleanup needed		Slight	Slight (decomposition products)	Electrical parts; general cleanup needed

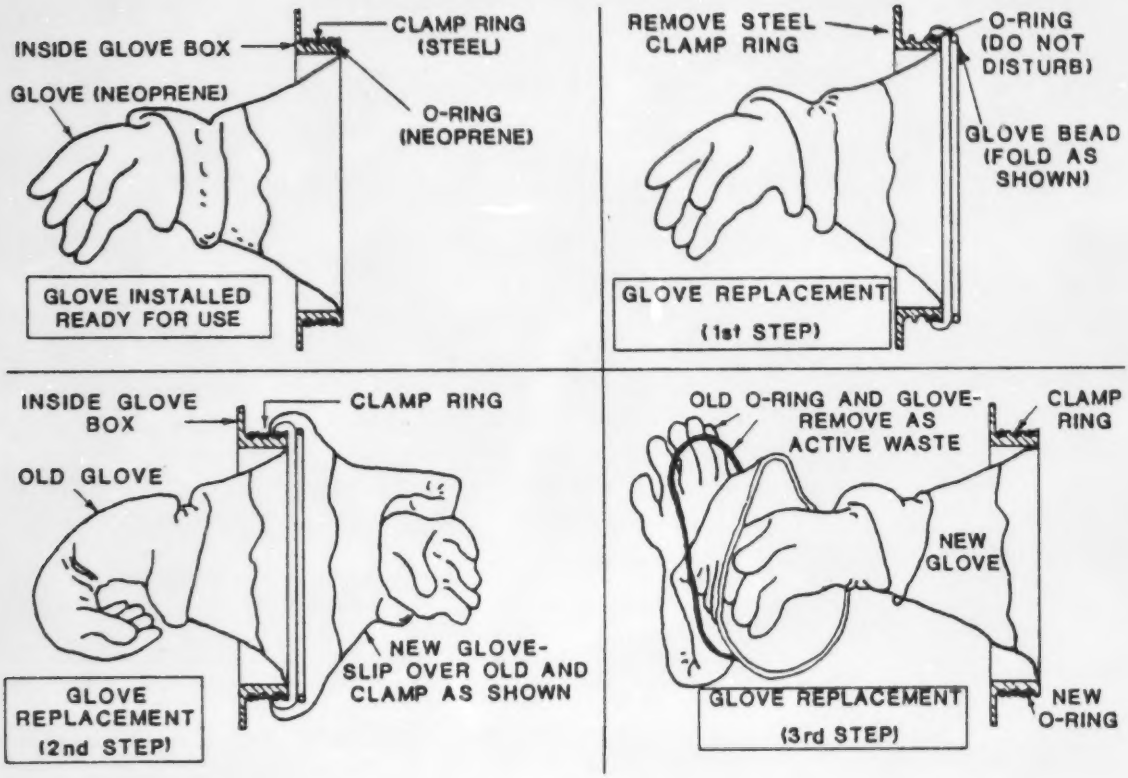
REPLACEMENT OF A GLOVE BOX GLOVE

Prior to using a glove box, the operator should inspect the O-rings, gloves, and the Magnahelic gage. If an O-ring is broken or badly cracked, the operator should replace it. If there is a cut, crack, or hole in the glove itself, the procedure outlined below should be initiated. Gloves must be changed in a very careful manner to avoid breaking the glove containment.

A health physics representative should be notified about the problem immediately. If the ruptured area is easily accessible, a piece of tape should be placed over the rupture area if approved by the health physicist. Do not attempt to tape the ruptured area if it is difficult to reach. Smears should be taken of the glove and surrounding area to determine if the exterior environment has been contaminated. The area should be surveyed with appropriate radiation-detection devices. If the surrounding area is not contaminated, the replacement of the glove should proceed as explained below. If the area is mildly contaminated, it should be decontaminated or secured prior to the glove change.

A plastic bag should be taped to the front of the glove box underneath the glove port of the ruptured glove. In a cautious manner, the ruptured glove should be positioned so that it extends into the box. The technician should inspect and check each new glove for air leaks by rolling up the open end to compress the air in the glove into the hand and finger sections. If air can be heard escaping, another glove should be used to replace the damaged one.

The steps of the glove replacement are demonstrated in Figure 25-2-4a and b. In sequence, the steps in replace-



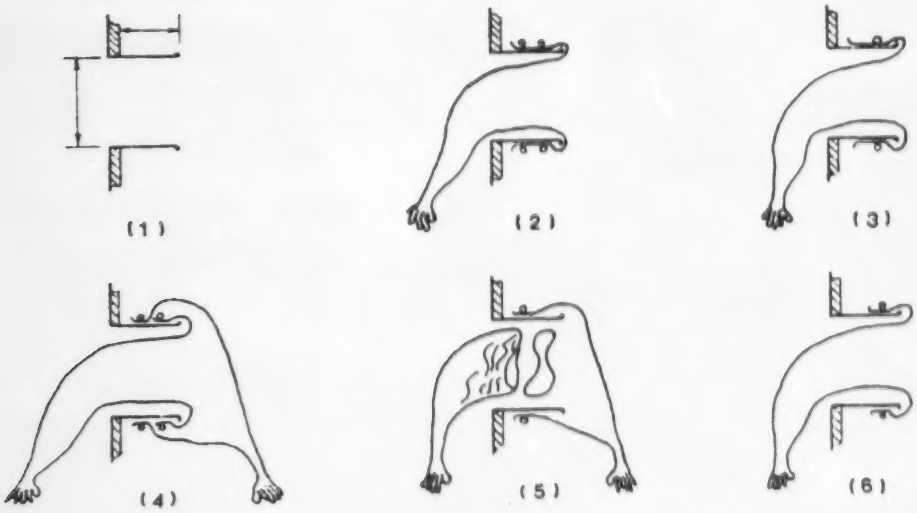


Figure 25-2-4. Glove replacement.

ment of the damaged glove are as follows:

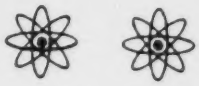
1. Remove the O-ring from the outer groove of the glove port.
2. The thick end of the old glove should be moved from the inner groove of the glove port to the outer groove.
3. The thick end of the new glove should be placed over the old glove and pushed to the back of the glove port.
4. The O-ring should be placed in the inner groove, thereby sealing the new glove.
5. Working through the other glove in the adjacent port, the technician should remove the old glove from the glove port into the inside of the glove box.
6. The O-ring should be rolled to the outer groove over the new glove, and the thick end of the new should be slid into the inner groove.
7. A health physicist should check for contamination.

Some glove box facilities require that two external O-rings secure the glove to the glove port. Other glove boxes require an O-ring and a metal band, with which the glove is attached to the glove port as in Figure 25-2-4a.

EXERCISES

1. Find the maximum size of particle of plutonium that may be inhaled without exceeding the maximum permissible lung burden of plutonium. Assume that the particle is spherical and stays in the lung without dispersing. In relative terms, is it microscopic in size?

2. Research the use of welders' glove boxes. What unique hazards does the use of a welder present in a glove box? Elaborate on the possible need for an inert atmosphere in the box for certain welding operations.
3. Research and explain the conditions that could produce a plutonium fire if plutonium carbide, plutonium oxide, and plutonium nitrate are being processed. Particularly note the temperatures of ignition and the oxygen requirements. Which of these – or should all of these – compounds be handled in inert atmospheres?



MATERIALS

Film badge.
Pocket dosimeter.
Portable survey meter.
Long-sleeve contamination coveralls.
Rubber gloves.
Eye protection.
Shoe covers.
Glove box with sphincter and air lock.
Plastic/polyethylene for bag-out ports.
Bag sealer.
Laboratory glassware.
Metal container for glassware.
A solid, nonradioactive powder to be used as a simulated contaminant.

PROCEDURES

NOTE: All operations are to be conducted in a simulated, limited-access environment. The student will be told that there is a contaminated sample somewhere in the laboratory. The instructor will prepare the nonradioactive powder sample, the cut glove, and the cut bag used in this Procedure.

1. Carry the sample to the glove box, using proper health physics techniques.
2. Transfer the sample into the glove box, using proper procedures as learned in Module 25-1, "Glove Box Operations – Fundamentals."
3. Take a 1-ml sample of the powder, and dilute it with 10 ml of water. At this point, the student will discover that the glove is damaged.
4. Before going any further, change the glove to prevent the spread of contamination, following the procedure outlined in this module.
5. The glove was cut because a beaker broke during the procedure defined in Step 4. Bag in the items needed to clean up the solution and the fragments of the broken beaker.
6. Bag out the solution prepared from the powder sample; transfer it to the laboratory for analysis. However, in bagging out the defined liquid sample, the student will encounter a cut in the plastic bag. Correctly rebag the solution.
7. Remove and dispose of the solid material left in the glove box.

DATA TABLE

None.

Blatz, H. ed. Radiation Hygiene Handbook. New York: McGraw-Hill Book Company, Inc., 1959.

Design of and Equipment for Hot Laboratories. Proceedings of a Symposium sponsored by the International Atomic Energy Agency in Otaniemi, August 2-6, 1976.

Eichholz, G.G., ed. Radioisotope Engineering. New York: Marcel Dekker, Inc., 1972.

Glovebox Fire Safety: A Guide for Safe Practices in Design, Protection and Operation. TID-24236 (1967).

Howell, L.N. and Pierce, E.E. "Glove-Box and Hot-Cell Design Considerations." Nuclear Safety 3 (1962).

Howell, L.N. "Safety in Glove-Box Design and Operation." Nuclear Safety 5 (1964).

Kelman, L.R.; Wilkinson, W.D.; Shuck, A.B.; and Goertz, R.C. "Handling Alpha-Active Pyrophoric Materials, Parts 1-3." Nucleonics 14, #3, 4, and 5 (1956).

Fill in the blanks with the appropriate terms:

1. The two most common industrial hazards that lead to the spread of contamination when pyrophoric materials are handled in glove boxes are _____ and _____ _____.
2. Glove boxes may be used to protect the _____ or to perform an operation in a _____ environment.
3. Glove box criticality may be prevented by limiting the _____ of fissile material present in any phase of the processing.
4. When large quantities of fissile material must be handled, criticality can be controlled by geometric _____ and size.
5. _____ _____ is the most effective long-term glove box structural material.
6. If visibility allows, _____ _____ should provide the best window material.
7. If as much sensitivity must be retained as achievable by the operator, _____ gloves are preferred over _____ gloves.
8. Hypalon gloves offer more protection from alpha and beta radiations since they are _____ than neoprene gloves.
9. Two of the industrial safety problems concerned with the use of glove boxes and which lead to fatigue of the operator are _____ _____ and the _____ _____ at which operations must be carried out.
10. A punctured glove must be replaced without _____ the glove box containment.

ESSAY QUESTIONS:

11. Discuss the handling of penetrations into glove boxes for metallurgical operations. Emphasize the sealing of rotating parts. Comment on the location of as much of the associated machinery outside the glove box as possible.

12. Describe the kinds of radioactive materials that can be processed in glove boxes without extra shielding. Comment on what hazards exist with each kind.

13. List and comment on each of the general design considerations necessary in designing a glove box for a specific industrial process.

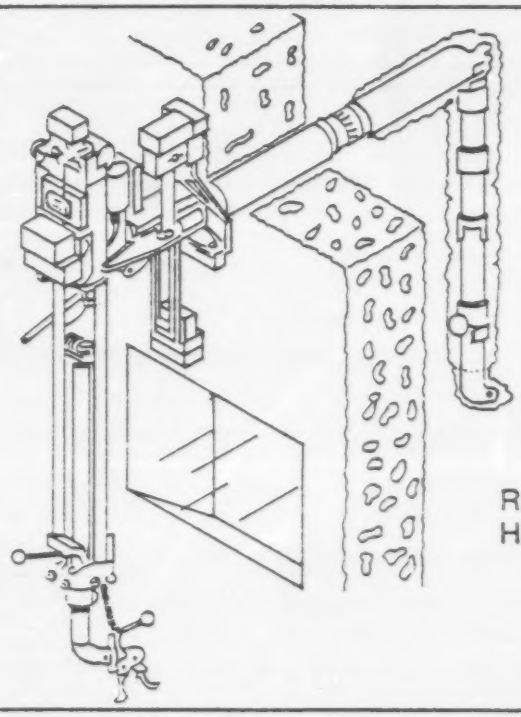
14. Describe any special features or safety procedures to be instituted in the use of a glove box for the processing of aqueous solutions of plutionium.

15. Expound on the fire and explosion hazards, as well as their prevention and control, when pyrophoric substances are used in the glove box.

NUCLEAR TECHNOLOGY

MODULE 25-3

MASTER/SLAVE MANIPULATORS - FUNDAMENTALS



RADIOACTIVE MATERIAL
HANDLING TECHNIQUES

COURSE 25

ORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

Master/slave manipulators are remotely controlled mechanical devices used to handle radioactive materials safely. They are operated and controlled from outside heavily shielded enclosures called "hot cells." These cells contain the radioactive material and provide a barrier that reduces levels of ionizing radiation. The material itself is viewed through shielded viewing windows or periscopes.

Manipulators have been in use in the nuclear industry for over thirty years. They provide a safe means of handling radioactive materials and are used to perform many intricate tasks. Figure 25-3-2, page 7, illustrates a typical manipulator. The master end of the manipulator controls the operations of the slave end.

The movements of an operator's hands on the manipulator's master control handle are mechanically transferred to the slave end through an ingenious system of cables, tapes, and electrical devices. The slave end, becomes, in effect, the operator's hand and is capable of duplicating all of its master's movements. Total attention is focused on the process inside the cell as the operator's fingers expertly maneuver the master control.

To learn to operate the manipulator requires patient study and practice. This module introduces the manipulator, identifies its components, and discusses the control of its mechanical actions. Proper gripping, lifting, and pushing procedures are outlined. The Procedures section describes a step-by-step method by which the student can learn how to operate the manual motions of the manipulator.

MODULE PREREQUISITES

None.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
   a. Master control handle.
   b. Master boom tube.
   c. Master trunk tube.
   d. Through tube.
   e. Slave boom and slave trunk tubes.
   f. Extension tube.
   g. Boot.
   h. Tong.
   i. Operating gallery.
   j. Cell.
   k. Viewing window.
   l. Shielding wall.
2. Locate components "a" through "h" on an unlabeled sketch of a manipulator, and label them correctly.
3. Given an unlabeled sketch of the master control handle, correctly label the following parts:
   Stabilizer.
   Grip cable.
   Grip pulley.
   Grip lever.
   Ratchet lever.

4. Describe these phrases:
   Grip motion.
   Azimuth motion.
   Wrist motions (elevation and twist).
5. Describe the purpose of ratchet action and how it is engaged and disengaged.
6. Describe the tong squeeze alarm system explained in the module.
7. Given two sketches that illustrate proper and improper gripping procedures, identify a sketch that depicts the proper procedure; and explain why the procedure depicted in the other sketch is incorrect.
8. Describe the mechanical actions that occur when tong fingers make contact with an object.
9. Given sketches that illustrate proper and improper lifting and pushing procedures, identify sketches that show the proper procedures; and explain why procedures depicted in the other sketches are incorrect.
10. Describe the mechanical limitation of twist motion. Summarize the consequences of forcing wrist gear assembly beyond this limit.
11. Perform the following manual operations with the master/slave manipulator:
    a. Grip and lift an iron block weighing two kilograms. Lower it to a position one foot to the left of original position and release it.
    b. Transfer position of three wooden blocks placed on top of each other in accurate vertical alignment.
    c. Unscrew threaded top of a container.

Manipulator operations are remote and are carried on at a distance. The operator stands in the operating gallery behind a shielding wall, looking into the cell through a heavily shielded viewing window (Figure 25-3-1).

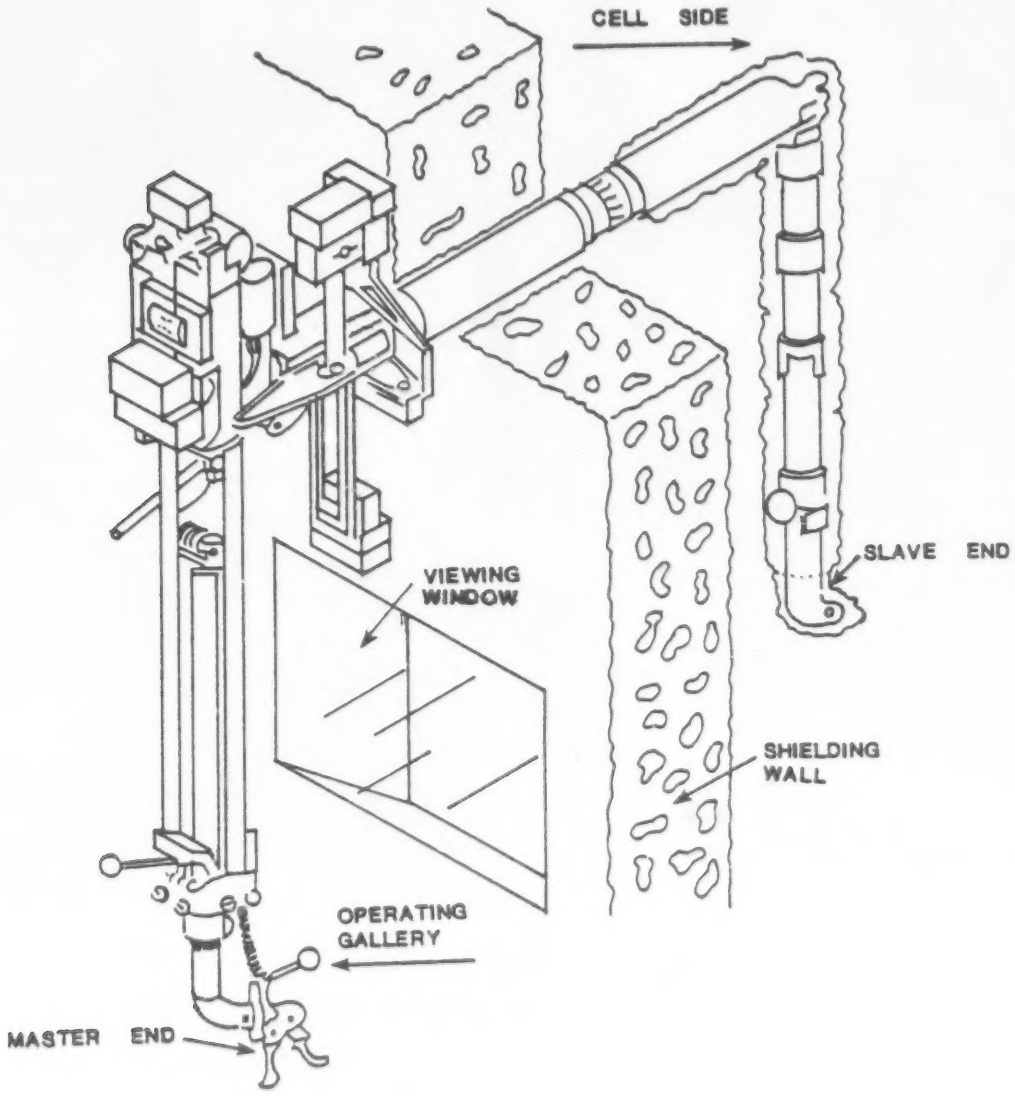


Figure 25-3-1. Master/slave manipulator.

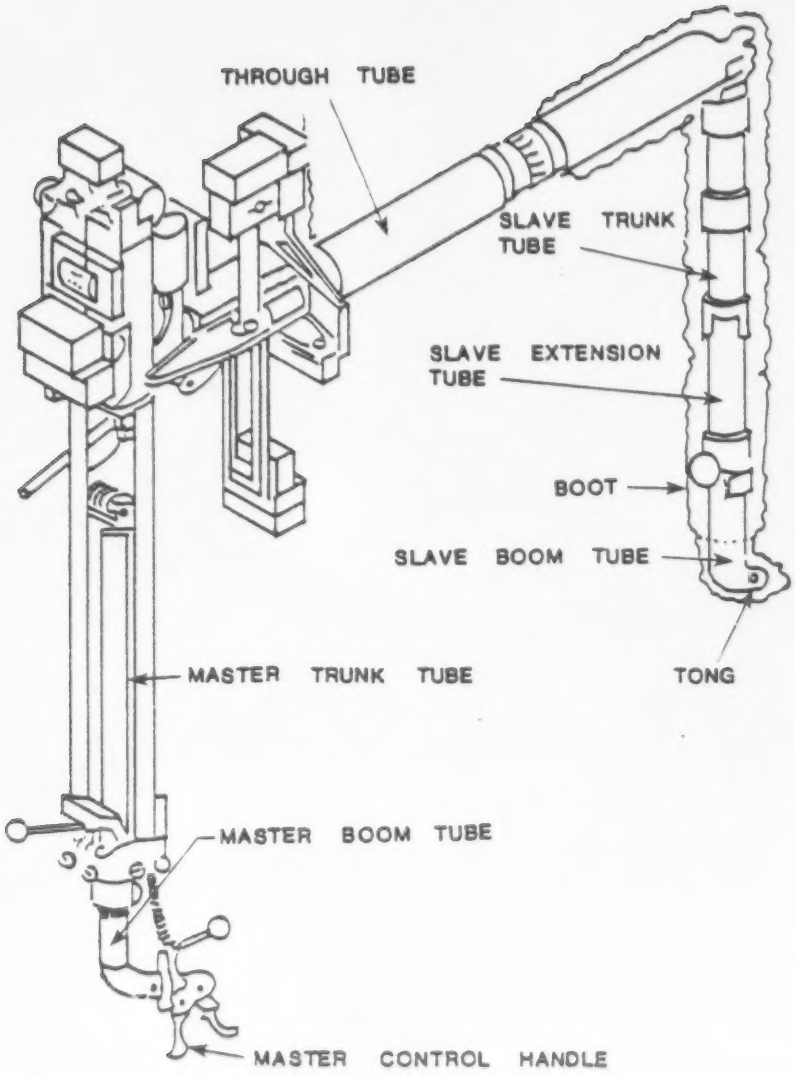


Figure 25-3-2. Master/slave manipulator components.

The major components of the master/slave manipulator are depicted in Figure 25-3-2.

The master control handle, sometimes called the "two-speed handle," is the control device used to perform manipulator operatons. The operator should hold the handle waist high with one hand about a foot away from the body. Movements made with the master control handle are transferred to the slave end.

The master boom tube can be raised or lowered manually to raise or lower the slave boom tube. When the master control handle is rotated, this tube turns; and through a system of gears and tapes, the motion is duplicated mechanically at the slave end.

The master trunk tube and the slave trunk tube house the cables and pulleys that transfer motion.

The through tube is that part of the tube that goes through the cell wall.

The slave boom tube is the counterpart of the master boom tube. It can be rotated, extended and retracted to match the motion of the master tube.

The slave extension tube extends the range of motion of the slave boom tube. It can be retracted electrically and extended beyond the manual limits of the slave end. In one type manipulator it can increase the lengthening movements of the slave boom tube by 32 1/4 inches. It is also used to lift heavy objects when the slave arm is in the vertical position.

The tong is the manipulator's mechanical "hand." It holds and squeezes objects. The actual grasping mechanisms are the fingers.

A protective polyurethane covering called the "boot" encloses most of the slave end. Only the fingers are left

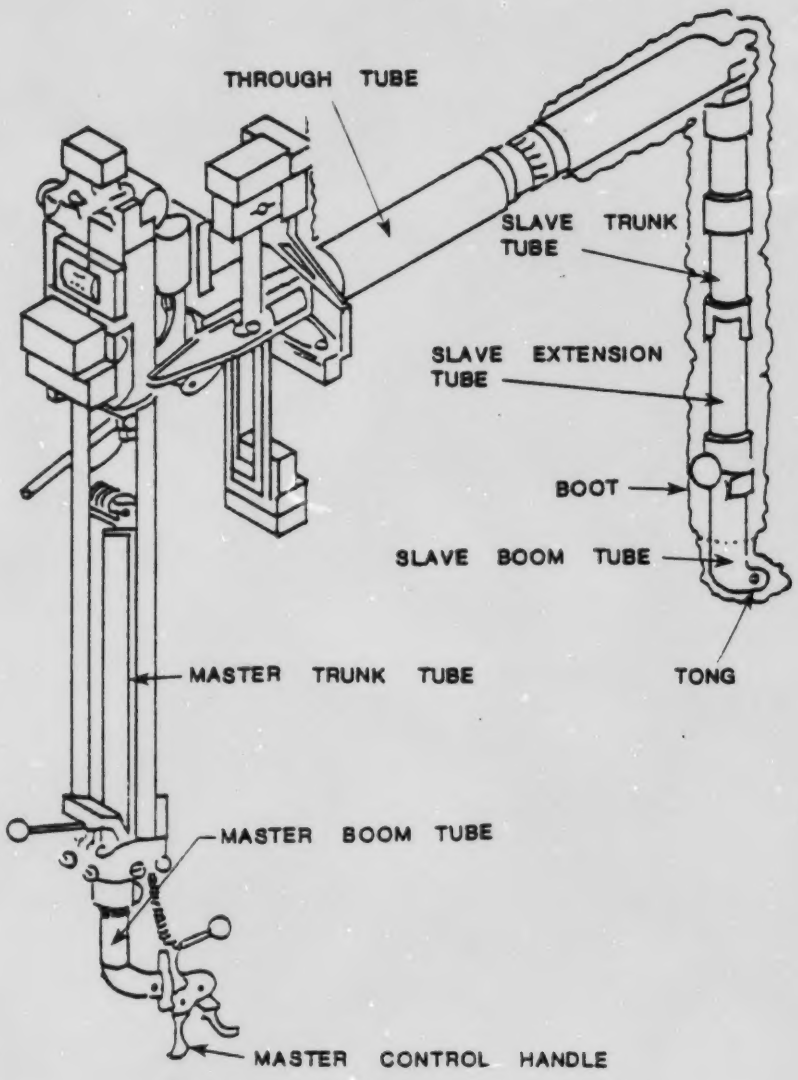


Figure 25-3-2. Master/slave manipulator components.

uncovered. This covering provides an air seal and protects against radioactive contamination and chemical vapors.

MANUAL MOTIONS

Motions performed by the manipulator are of two types: (1) manual motions and (2) electrical indexing motions (discussed later in this module). Manual motions are grip, azimuth, and wrist motions and motions with which the slave boom tube is raised and lowered. All these operations are perfomed with the hand on the master control handle (Figure 25-3-3).

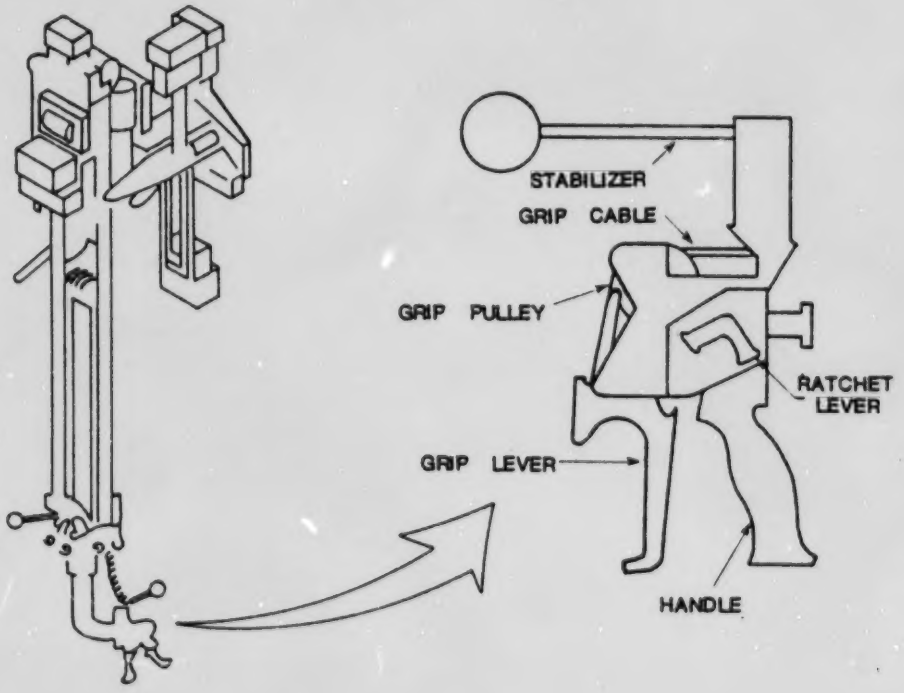


Figure 25-3-3. Master control handle.

To assume the proper operating position, the operator stands holding the master control handle waist high. The operator does not look at the handle but directs all attention towards the work going on in the cell.

Gripping Motion

Gripping at the slave end is accomplished by two mechanical fingers installed in the tong. When the grip level is squeezed toward the handle (Figure 25-3-4), the slave end tong closes (Figure 25-3-5) with a force equal to the pressure on the grip lever. As soon as the fingers make

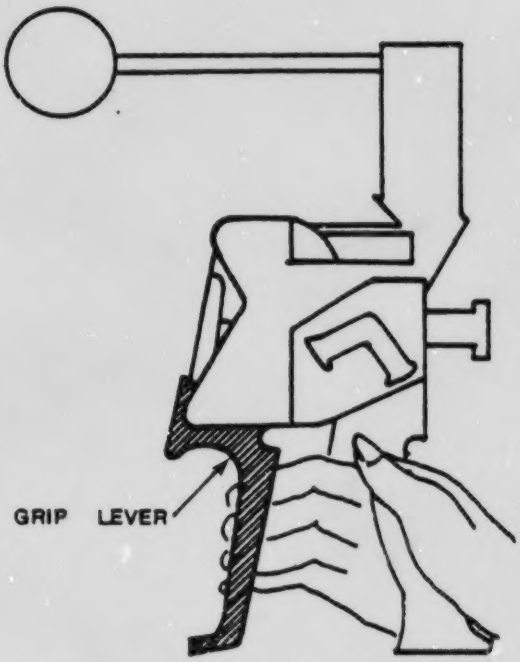


Figure 25-3-4. Gripping is controlled by the grip lever.

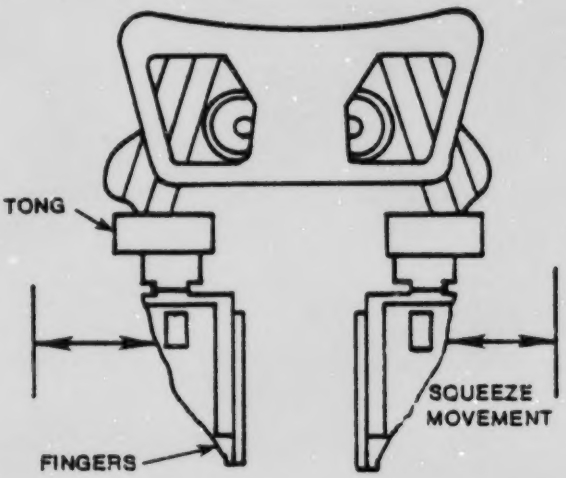


Figure 25-3-5. Closing motion.

contact (Figure 25-3-6), the tongs automatically apply more pressure to the object being held. This transference of motion is accomplished through a series of pulleys and cables leading from the master to the slave end. Pulling of the grip lever towards the handle winds the cable on the grip pulley (Figure 25-3-7). This tightens the grip cable, which, in turn, pulls the tong cable. The tong cable pulls the tong closed.

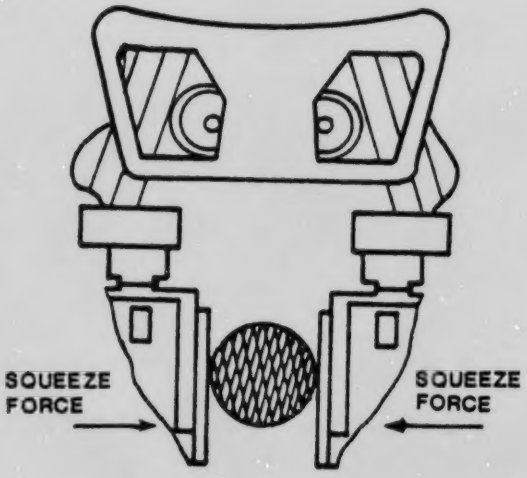


Figure 25-3-6. When the fingers make contact, more pressure is automatically applied.

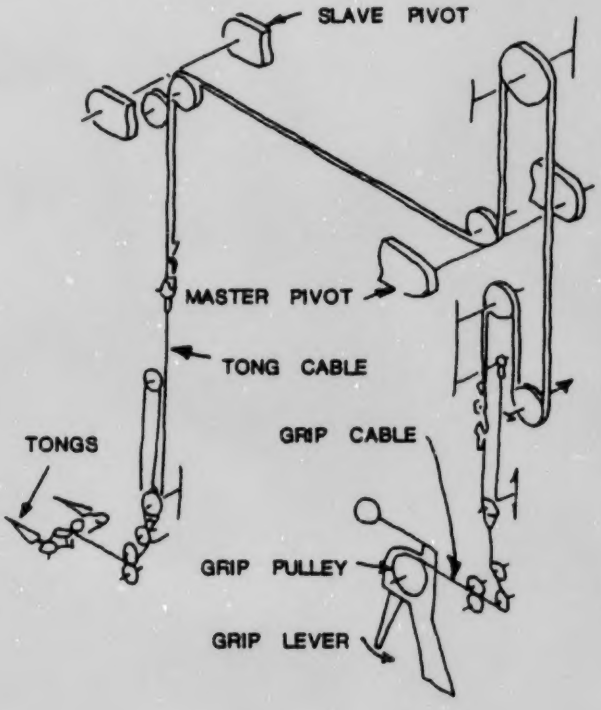


Figure 25-3-7. Tong motion.

The master control handle is equipped with a ratchet lever, which allows the operator to maintain the squeeze force on an object while the grip lever is released. It also allows the operator to increase the squeeze force by "pumping" the grip lever (Figure 25-3-8). The ratchet lever is engaged by being pushed with the thumb. It is disengaged when the grip lever is squeezed and the ratchet is released (Figure 25-3-9).

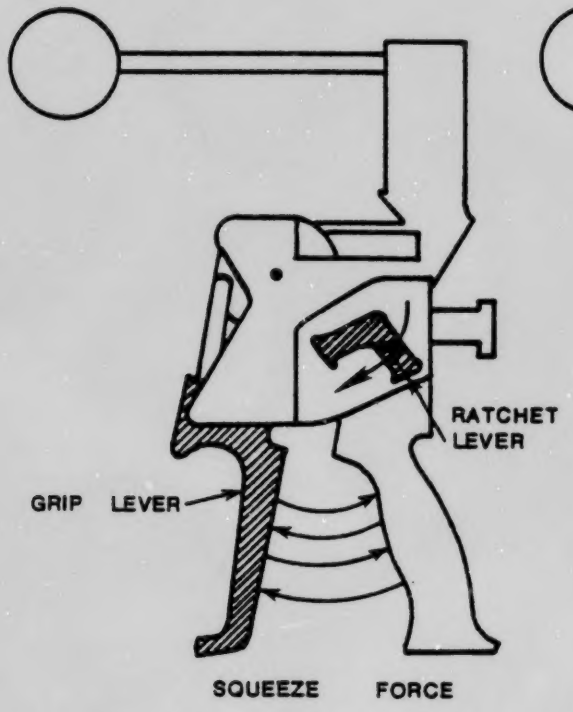


Figure 25-3-8. Squeeze force can be increased by pumping grip lever.

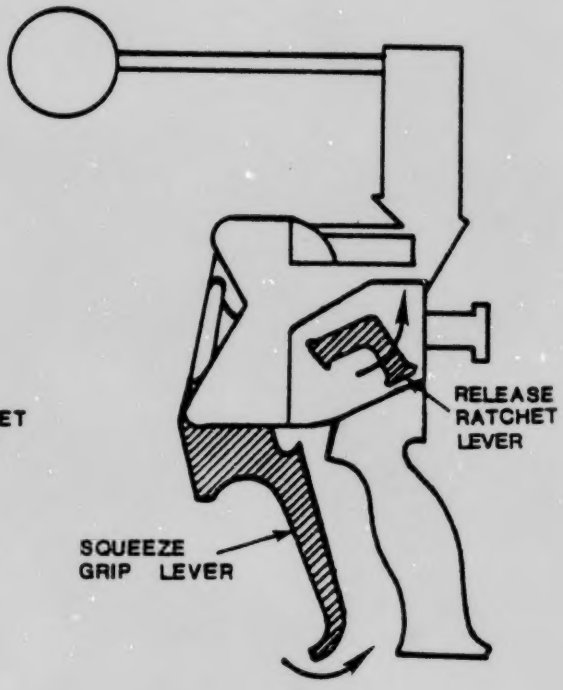


Figure 25-3-9. Disengage ratchet action by releasing ratchet lever while squeezing grip lever.

The operator must be careful to apply only the force necessary to handle an object. The tong tapes easily can be broken. Most units are equipped with a tong alarm, which

can be set to allow an operator to handle an object properly. When too much pressure is applied, the tong alarm sounds. This alarm is a signal to reduce immediately the pressure exerted. Otherwise, the manipulator may be damaged.

Objects must be gripped properly by the manipulator (Figure 25-3-10a). Improper gripping can cause the tongs and the fingers to become distored and misaligned. Large objects, especially, should not be gripped too far back into the fingers (Figure 25-3-10b).

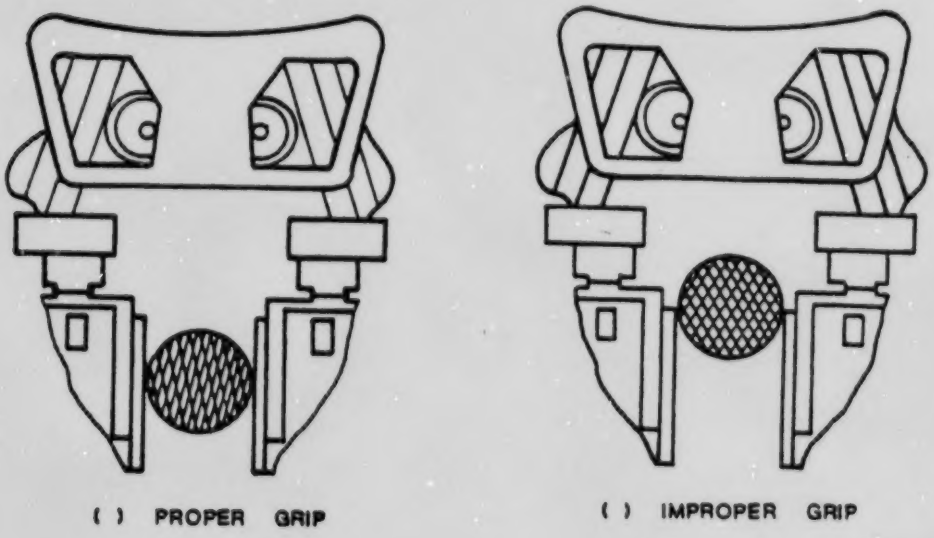


Figure 25-3-10. Proper and improper gripping.

Azimuth Motion

The human wrist is capable of a variety of motions. It can rotate, move up and down, and move side to side. The

azimuth motion duplicates this side-to-side movement. This motion moves the tongs left and right in a horizontal plane (Figure 25-3-11). It is made when the master control handle is rotated. A series of gears and cables transfer this motion to the slave end tongs (Figure 25-3-12).

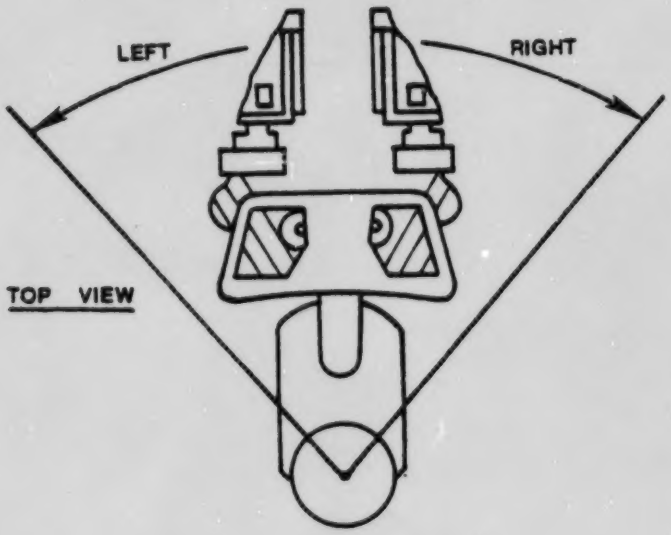


Figure 25-3-11. Azimuth motion.

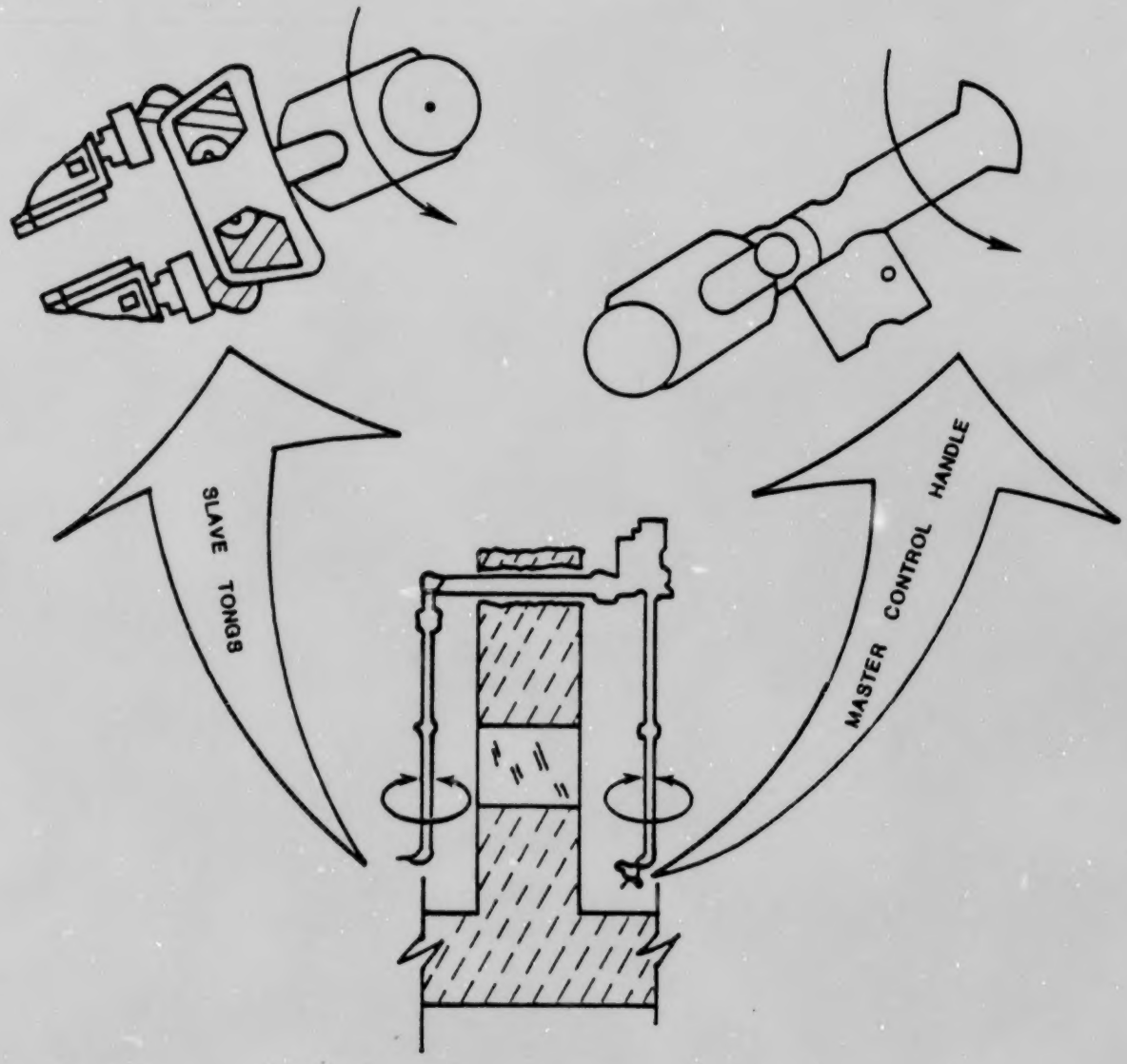


Figure 25-3-12. When the master control handle is rotated, the tongs rotate.

Wrist Motion

Wrist motion actually consists of two motions: elevation and twist.

The elevation motion moves the tongs up and down from a horizontal to a vertical position (Figure 25-3-13).

The twist movement rotates the tongs (Figure 25-3-14). The total range of motion of the tongs is 350°.

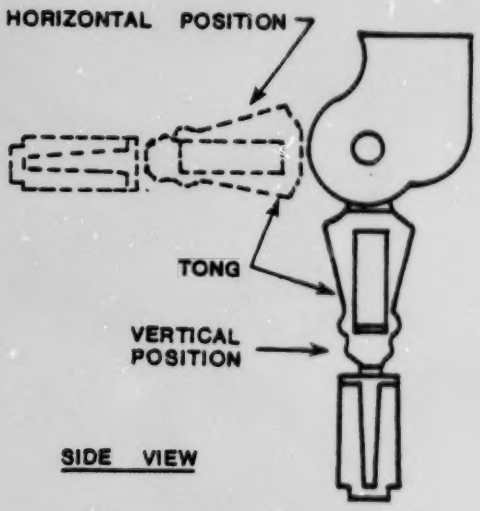


Figure 25-3-13.
Wrist motion.

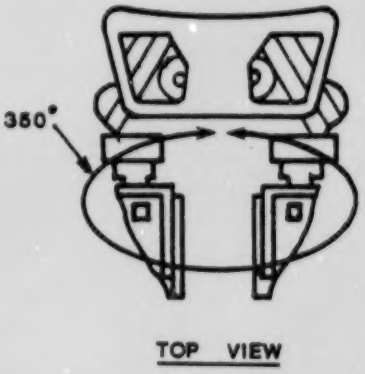


Figure 25-3-14.
Twist motion.

Both the elevation and the twist motions are controlled by the master handle. When the master handle is moved up and down, the slave wrist assembly moves up and down. When the master handle is twisted, the slave wrist assembly rotates. The master handle can be twisted only 175° left or right of center. It cannot be rotated 360°. There is a mechanical stop in the wrist gear assembly which can be destroyed when

an attempt is made to obtain additional twist movement. Excess pressure should not be applied to this stop.

Lifting and Pushing

The wrist yoke of a manipulator is one of the most delicate and most easily damaged components of the wrist assembly. Proper lifting and pushing can prevent such damage.

Heavy loads should always be lifted with the tongs in a vertical position. Figures 25-3-15 and 25-3-16 show why.

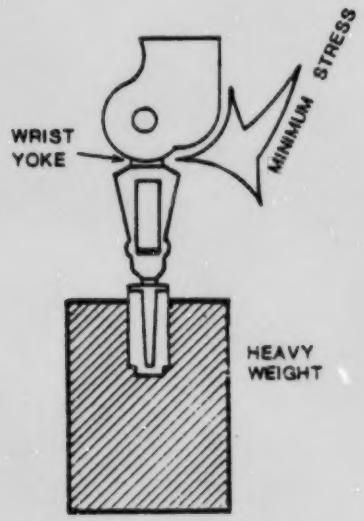


Figure 25-3-15. Proper lifting of heavy weight.

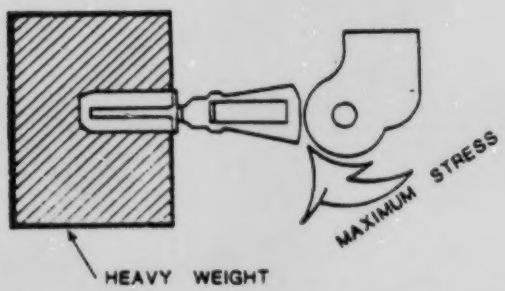


Figure 25-3-16. Improper lifting of heavy weight.

Maximum stress is placed on the wrist with the tongs held horizontally. When the tongs are held vertically, less stress is applied. The operator should imagine the slave end as an extension of the hand. Heavy loads normally are not lifted with the wrist held straight out from the body. When subjected to this kind of stress, the manipulator's wrist yoke shaft can snap off if a heavy load is lifted improperly.

The handling capacity of a manipulator is the amount of weight that can be handled with the tongs held in a horizontal position. Handling capacity usually is about 9 kilograms. Vertical position is always used for heavier weights. Whenever there is doubt, an object should be lifted vertically.

Improper pushing and pounding can damage the wrist yoke. Objects should be pushed with the tong fingers aligned with the direction of the push force (Figure 25-3-17). If the manipulator must be used to pound, another object should be used as a "hammer" to reduce the stress on the wrist mechanism.

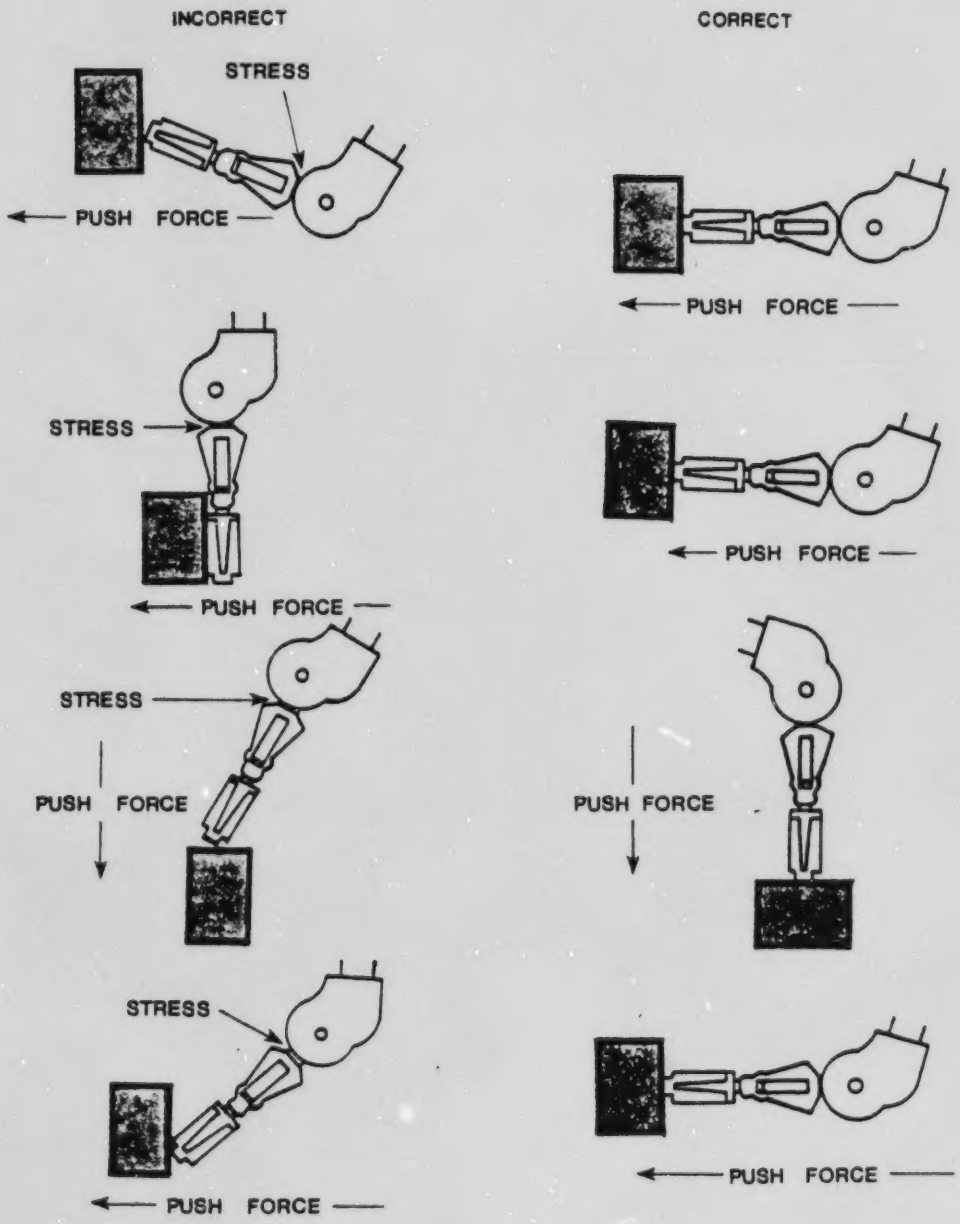


Figure 25-3-17. Correct and incorrect methods of pushing.

Raising, Lowering, and Stabilizing

The slave boom tube can be raised and lowered by raising and lowering of the master boom tube (Figure 25-3-18).

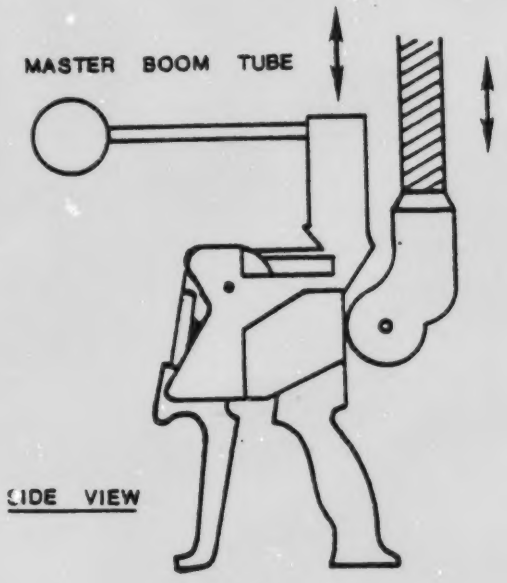


Figure 25-3-18. As the master boom tube is moved up and down, the slave boom tube moves identically.

The stabilizer handle (Figure 25-3-19) is used to steady the weights. With the master control handle in one hand and the stabilizer in the other, tong movement can be steadied; weight loads can be supported while the control handle is operated, and two-handed lifting can be performed.

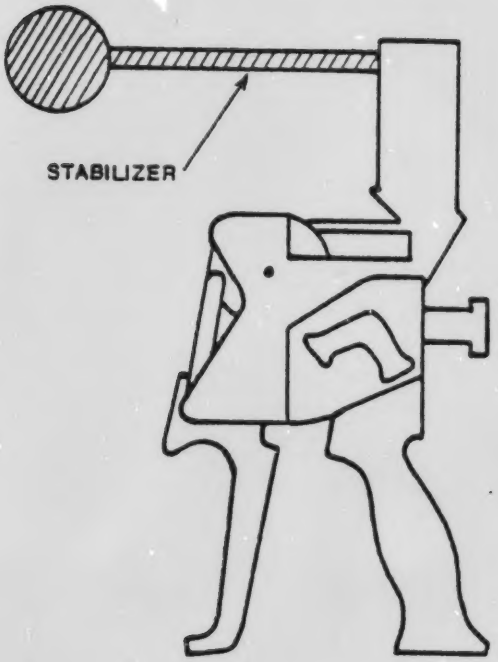


Figure 25-3-19.
Stabilizer handle.

ELECTRICAL INDEXING MOTIONS

The electrical indexing motions extend the range of the manipulator. With them, all the equipment within the cell can be reached. These motions are discussed in detail in Module 25-4, "Master/Slave Manipulator – Advanced."

EXERCISES

1. Write a step-by-step procedure that details the movements made with the master control handle to perform the following motions with the manipulator:
   a. Switch the positions of two wooden boxes placed on top of each other.
   b. Grip and lift an iron block weighing two kilograms, and lower it to a position approximately 30 centimeters to the left of the original position and release the block.
   c. Unscrew the threaded top of a container.
2. Write a brief paper (whose length is to be assigned by the instructor) that outlines the fundamentals of master/slave manipulators.

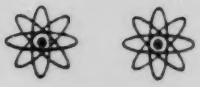
MATERIALS

1 master/slave manipulator in simulated cell.
2 wooden blocks.
1 pipe with pipe cap – diameter 5 centimeters, length 15 centimeters.
1 iron weight weighing two kilograms.

PROCEDURES

1. The instructor will demonstrate gripping, azimuth, and wrist motions and extension and retraction of slave boom. Proper operating position and proper gripping, lifting, and pushing procedures will be emphasized.

2. The instructor will demonstrate procedures detailed by Objective 11 (at beginning of module).
3. The student will perform simple motions with manipulator. Suggested sequence:
   a. Extension and retraction of slave boom.
   b. Gripping motion, emphasizing proper approach, proper grip, use of ratchet action.
   c. Combining a and b with use of stabilizer handle, emphasizing proper lifting procedure.
   d. Asimuth motion.
   e. Wrist elevation motion.
   f. Wrist twist motion, emphasizing mechanical limitations.
   g. Execute the procedures outlined in Objective 11.



DATA TABLES

None.

Central Research Laboratories. Master/Slave Manipulators.
Red Wing, MN: Central Research Laboratories, Inc.

1. Define the following terms:
   a. Master control handle.

   b. Master boom tube.

   c. Master trunk tube.

   d. Through tube.

   e. Slave boom and slave trunk tubes.

   f. Extension tube.

   g. Boot.

   h. Tong.

   i. Operating gallery.

   j. Cell.

k. Viewing window.

l. Shielding wall.

2. Use the unlabeled sketch (Figure 25-3-20) to locate and to label the following manipulator components:
   a. Master control handle.
   b. Master boom tube.
   c. Master trunk tube.
   d. Through tube.
   e. Slave trunk tube.
   f. Extension tube.
   g. Boot.
   h. Tong.

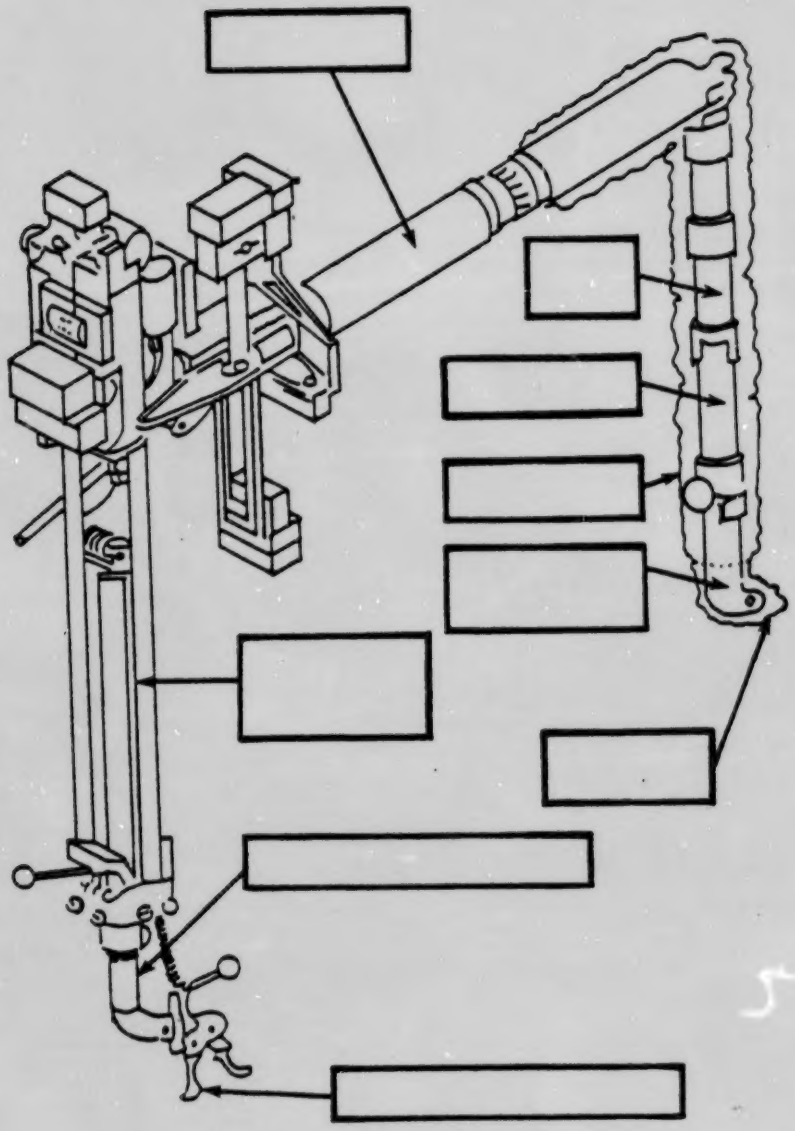


Figure 25-3-20. Master/slave manipulator.

3. Use the unlabeled sketch (Figure 25-3-21) to locate and label the following master control handle components:
   a. Stabilizer.
   b. Grip cable.
   c. Grip pulley.
   d. Grip lever.
   e. Grip adjustment.
   f. Ratchet lever.

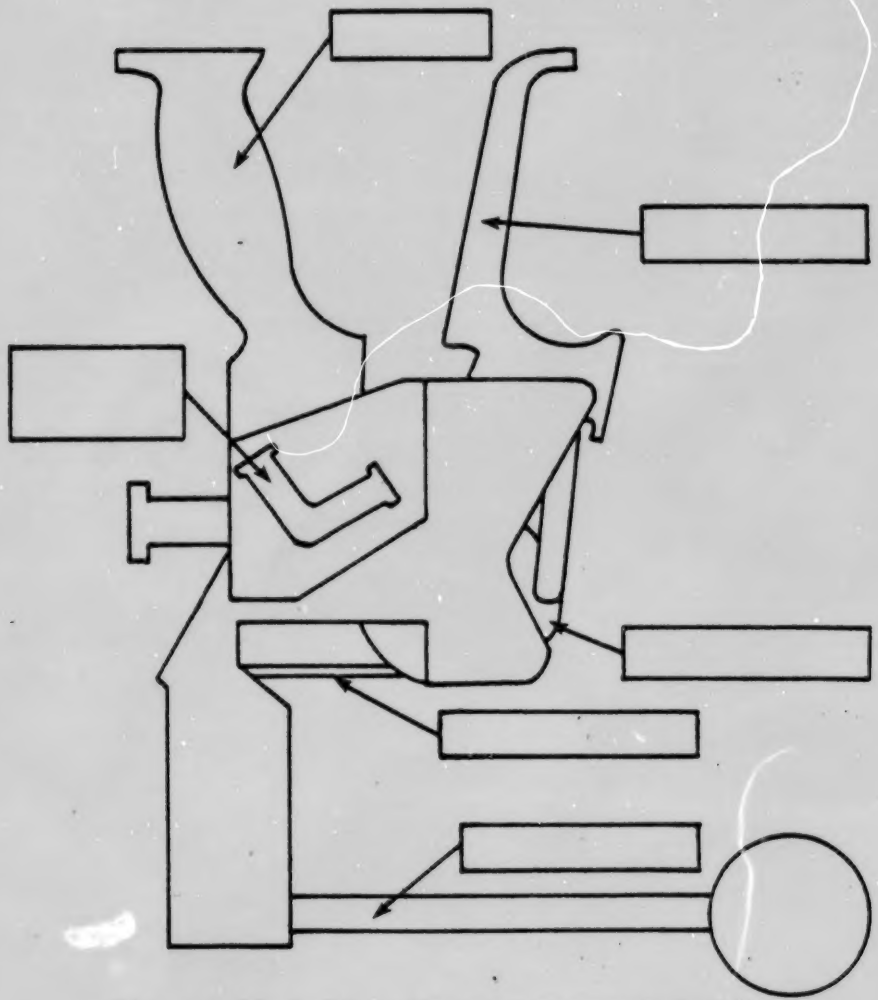


Figure 25-3-21. Master control handle.

4. Describe the following motions:
   a. Grip motion.

   b. Azimuth motion.

   c. Wrist motions (elevation and twist).

5. Describe the purpose of the ratchet action and how it is engaged and disengaged.

6. Describe the tong squeeze alarm system.

7. Which of the following sketches illustrates proper gripping procedure? Explain why the procedure shown in the other sketch is incorrect.

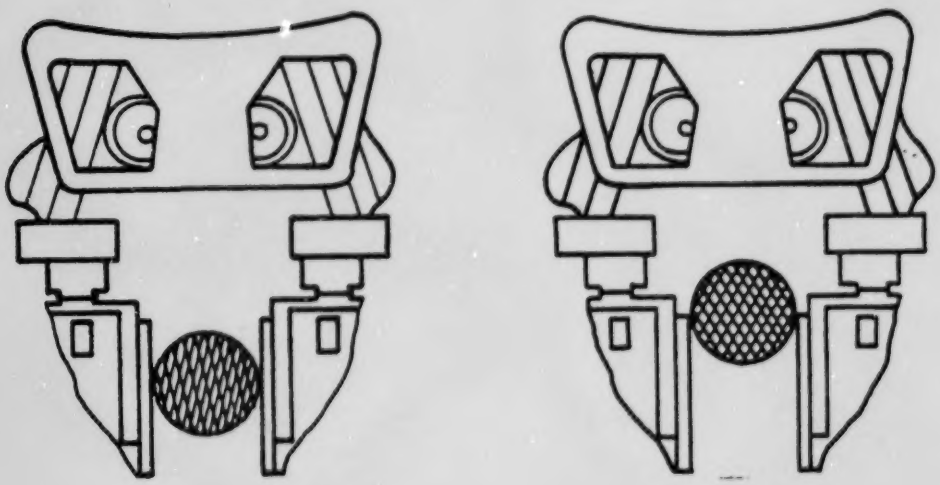


Figure 25-3-22. Proper and improper gripping.

8. Describe the mechanical actions which occur when the tong fingers make contact with an object.

9, Circle the sketches in Figure 25-3-23 that illustrate proper pushing procedures. Explain why the procedures shown in the other sketches are incorrect.

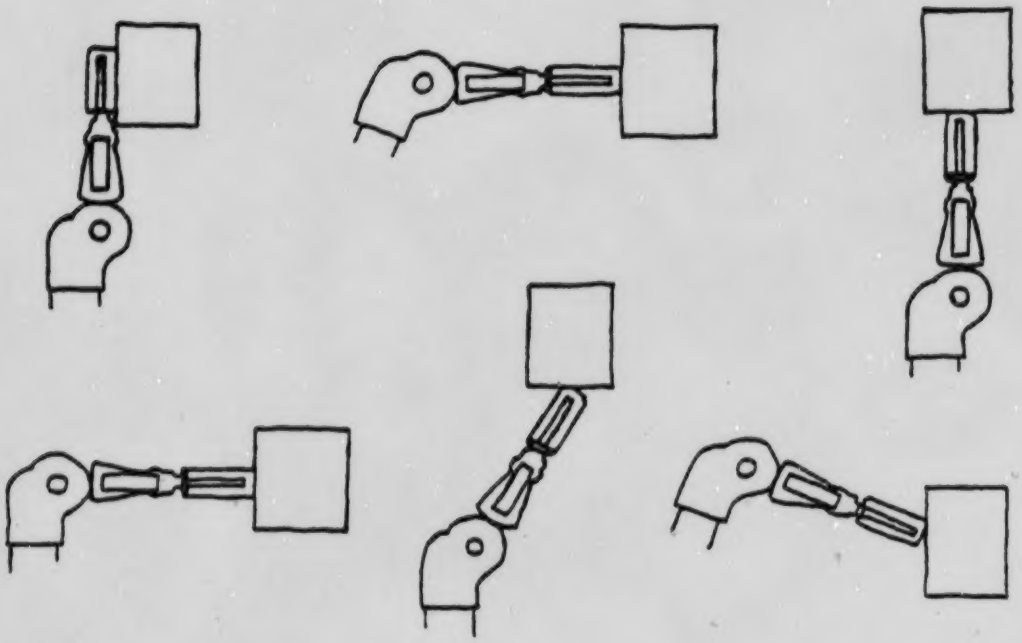


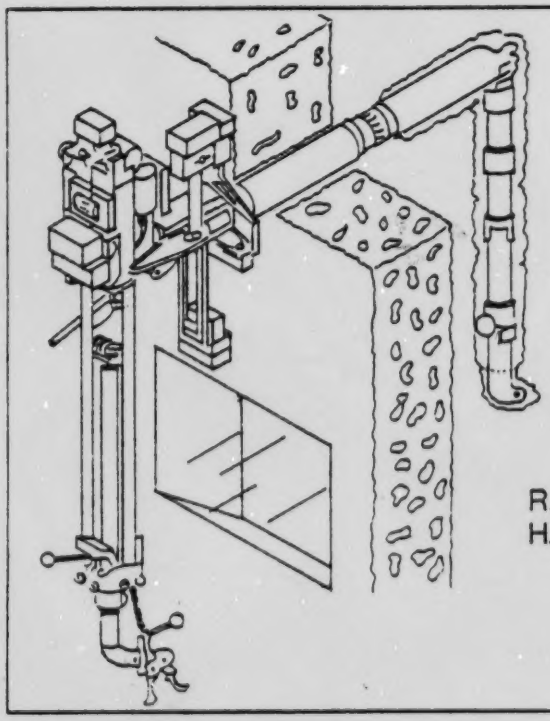
Figure 25-3-23. Correct and incorrect methods of pushing.

10. Describe the mechanical limitation of the twist motion. Summarize the consequence of forcing the wrist gear assembly beyond this limit.

NUCLEAR TECHNOLOGY

MODULE 25-4

MASTER/SLAVE MANIPULATORS - ADVANCED



RADIOACTIVE MATERIAL HANDLING TECHNIQUES

COURSE 25

ORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

Manipulators have both manual motions and electrical indexing motions. Manual motions, while allowing the operator to duplicate the motions of the human hand, permit only a limited amount of movement throughout the cell. Electrical indexing motions, however, provide the mechanical "hand" with a mechanical "arm." With them, manipulators can range freely throughout the cell and reach any object almost any place within it. They also allow the operator to hold the master control handle in a position that provides good vision through the viewing window.

Manipulators are also equipped with locking devices. These devices, called "motion locks," can hold objects in position and prevent movement of the manipulator.

This module discusses electrical indexing motions and explains their activation and use. Exercises at the end of the module allow the student to perform some fairly complicated manipulations. Mastery of this module and Module 25-3 is the first step towards beginning to master the operation of master/slave manipulators. These modules provide knowledge needed to understand how the manipulator works; skills required for the actual manipulations will come only through extensive practice.

MODULE PREREQUISITES

The student should have completed Module 25-3, "Master/Slave Manipulator – Fundamentals."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List and define three electrical indexing motions.
2. Given a sketch of the index controller, write a brief explanation of how three motions are activated, how motion speed is controlled, and how motion direction is selected.
3. Given a list of electrical indexing motions and a list of their mechanical limitations, identify motions and limitations that belong together.
4. Given a detailed sketch of the master end of the master/slave manipulator, including Y and Z, AZ, and WRIST motion locks, label locks correctly and describe how they are activated.
5. List two purpose served by the manipulator boot.
6. List three causes of common boot failures.
7. Describe boot leak; list one way it can be detected.
8. List two precautions that should be taken to protect the boot before and during manipulator operation.
9. List one precaution that should be taken to protect the boot after manipulator operation.
10. Use the master/slave manipulator inside a simulated cell to –
    a. Perform a finger removal.
    b. Install a threaded lid on a 5-centimeter by 15-centimeter pipe, place pipe behind a door, and close door.
    c. Return manipulator to "stored" position.

ELECTRICAL INDEXING MOTIONS

Electrical indexing motions are designated "X," "Y," and "Z." They are selected and activated by the index controller (Figure 25-4-1) located on the master control handle. The SELECT button allows the operator to select the proper indexing motion. Selection is changed each time the button is pushed. It is sequenced OFF-X-Y-Z-OFF. To select the Y motion from the OFF position, for example, the operator pushes the buttom twice. When a motion is selected a light

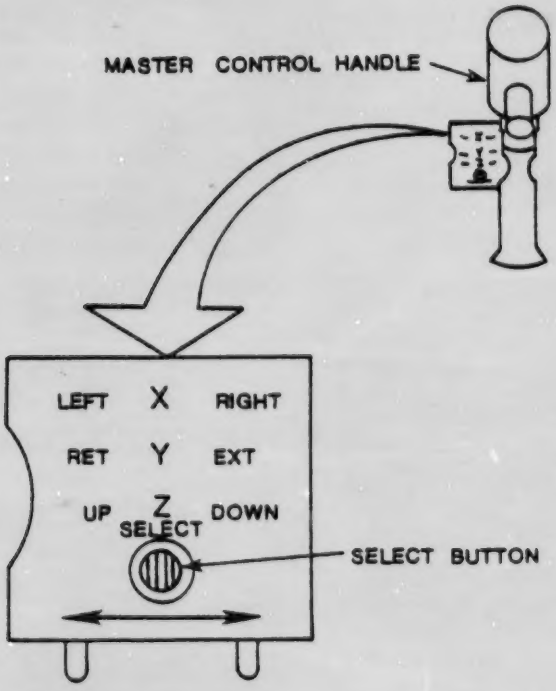


Figure 25-4-1. Index Controller.

on the index light panel (Figure 25-4-2) comes on. This panel is on the right side near the lower part of the master trunk tube (Figure 25-4-2). When the index controller is off, there is no light.

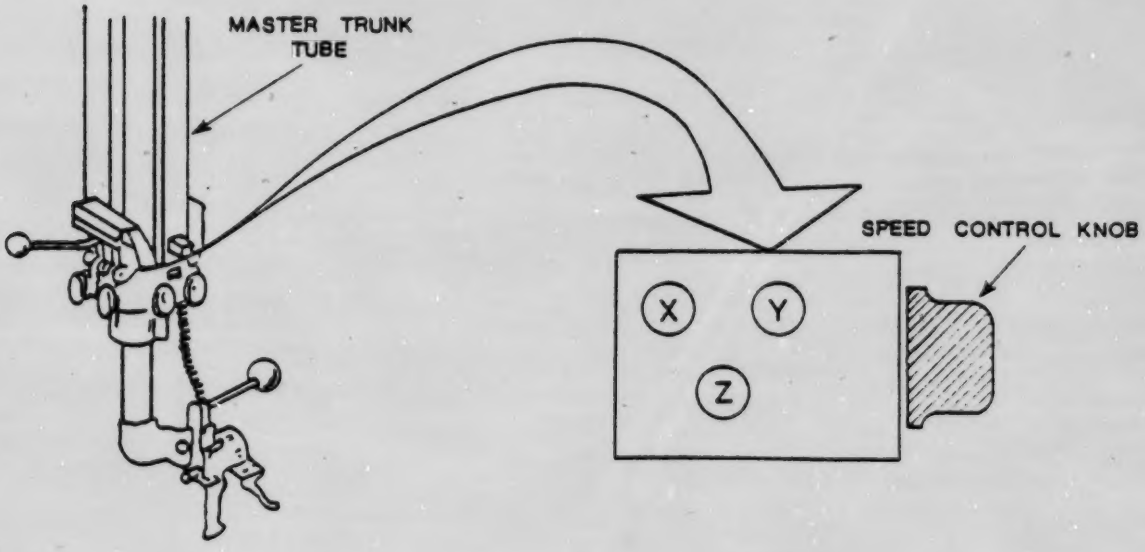


Figure 25-4-2. Index panel light and speed control.

The speed control knob is mounted on the side of the index light panel. When the knob is rotated clockwise, the motion speed increases. This speed should never be more than 3/4 of full sppeed. If the motion speed exceeds this limit, the manipulator will tend to drift after it is stopped. This uncontrolled motion increases the chances of an accident happening. Material within the cell may be knocked over or destroyed; the mechanism itself may jam. The X and the Y motions will not operate when the speed control knob is in the full counterclockwise position.

Motion is activated by the direction switch (Figure 25-4-3). When this switch is moved to the right, the manipulator moves to the right; when moved to the left, the manipulator moves to the left. The switch is spring loaded and will turn off when it is released.

The index controller should always be turned off when a movement has been completed. If it is left on, there is a chance that the operator who performs manual manipulations accidentally may activate the direction switch and cause the manipulator to collide with cell equipment or the cell wall.

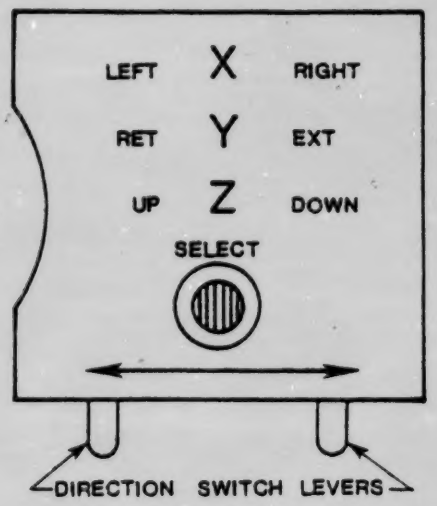


Figure 25-4-3. Index controller with direction switch.

THE X MOTION

The X motion moves the slave arm 20° left or right of the position of the master arm (Figure 25-4-4). Such movement allows the operator to stand at the viewing window with an unobstructed view of the operations going on within the cell. This motion also increases the lateral movement

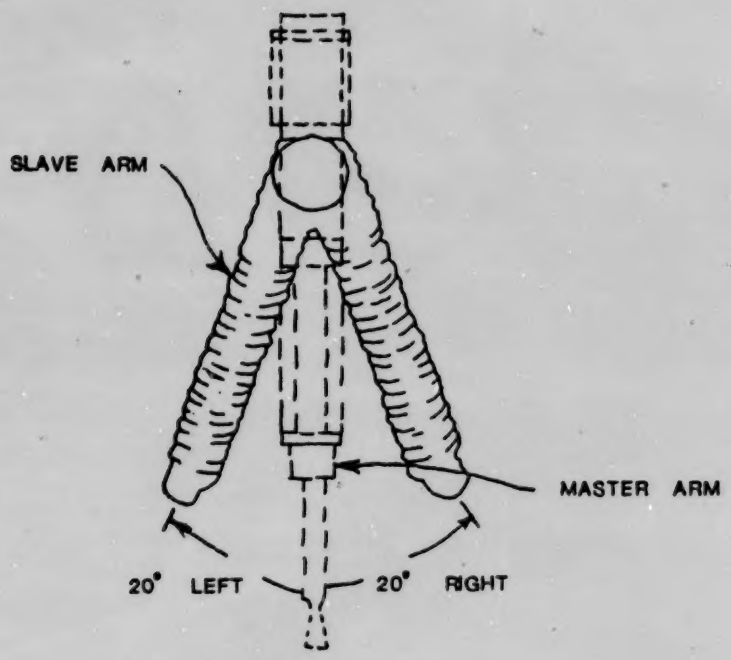


Figure 25-4-4. The X motion.

possible for the manipulator. With it, the operator can reach beyond the range of the right or left manual lateral movement.

Special precautions must be observed while performing this movement when two manipulators are in the same cell. All lateral movements are counterbalanced by the counter weights illustrated in Figure 25-4-5. If both manipulators are rotated in opposite directions at the same time, these weights could slam into each other (Figure 25-4-6).

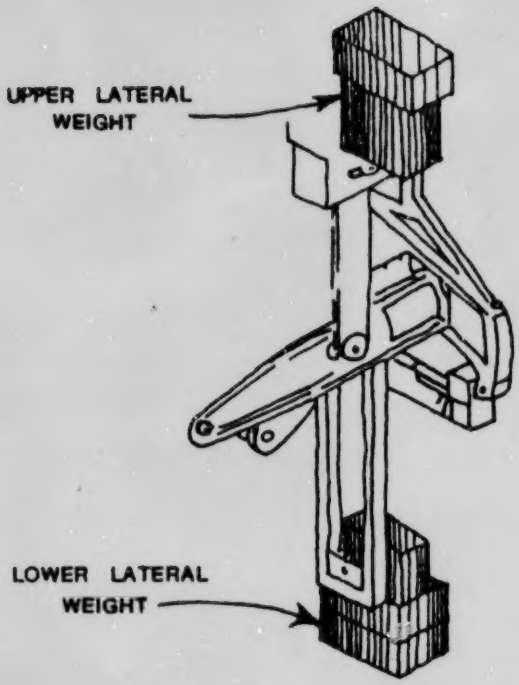


Figure 25-4-5. Counterweights.

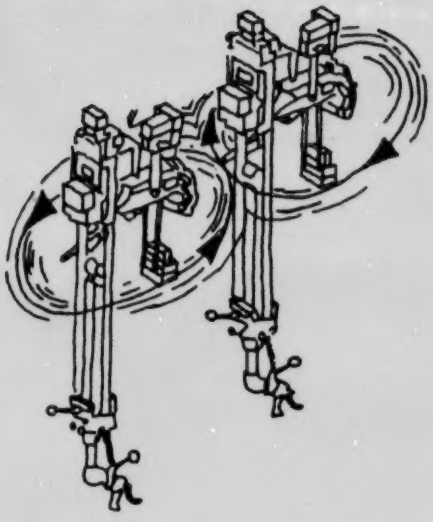


Figure 25-4-6. Lateral weights can collide.

THE Y MOTION

The Y motion can elevate or retract the slave arm. Figure 25-4-7 depicts the slave arm being elevated from a vertical to a horizontal position. The range of possible motion is 90°. The same figure depicts the slave arm moving 20° past the vertical position inward toward the master arm. These motions are called Y motions.

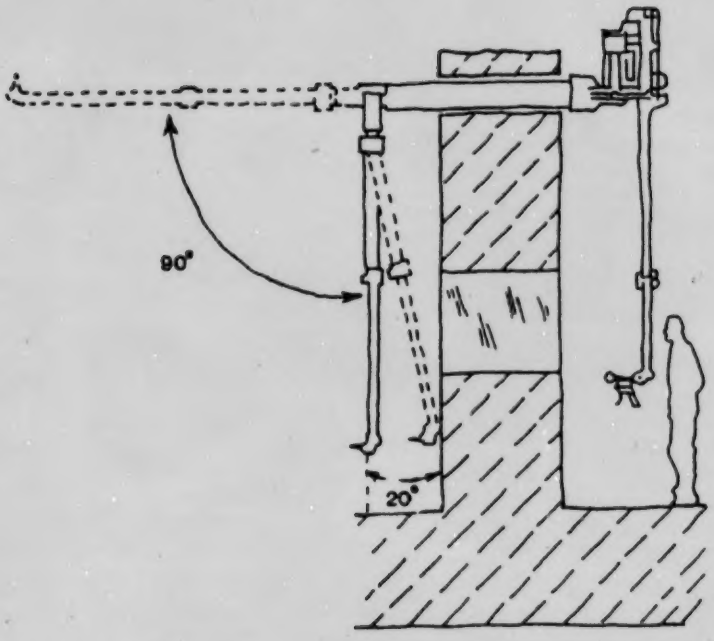


Figure 25-4-7. The Y motion.

THE Z MOTION

The Z motion allows the slave boom tube to be extended beyond the manual limits of the manipulator (Figure 25-4-8). It lengthens the reach of the manipulator's arm. When the Z motion is activated, the slave extension tube (Figure 25-4-9) moves outward.

When the manipulator arm is in the vertical position the power of the Z motion can be applied to the lifting of heavy weights. Such vertical lifting is performed with a load hook. Some manipulators can lift as much as 45 kgs.

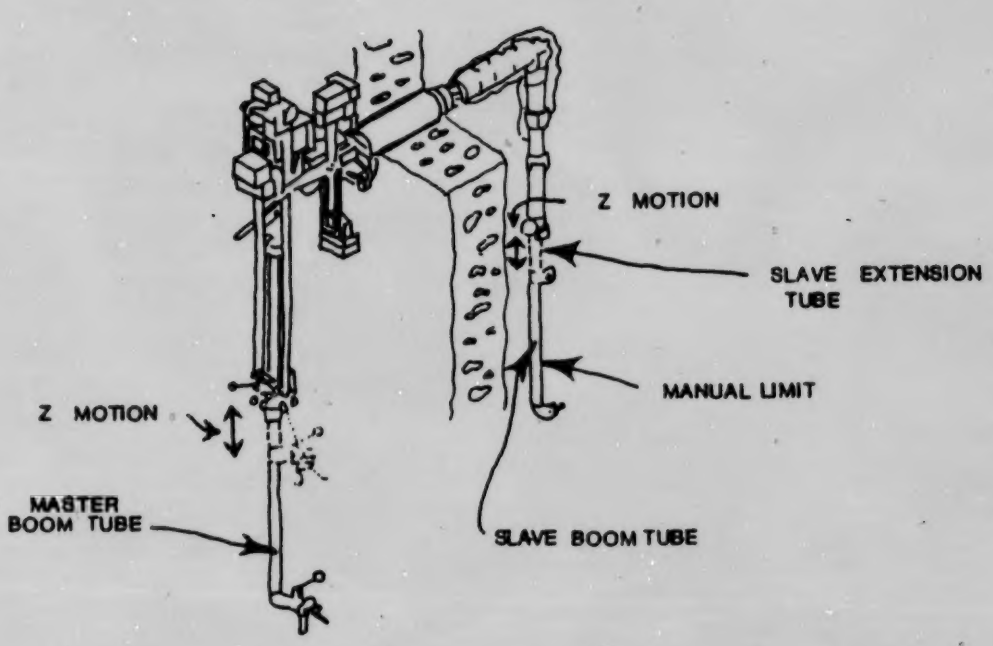


Figure 25-4-8. Z motion.

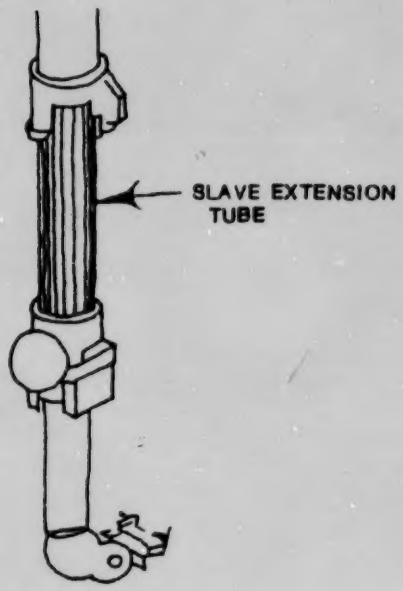


Figure 25-4-9. Slave extension tube.

MOTION LOCKS

It is possible to lock any electrical indexing motion and the azimuth and wrist manual motions. These locks are located on the master boom tube (Figure 25-4-10). They allow the operator to hold an object in position while performing manual movements.

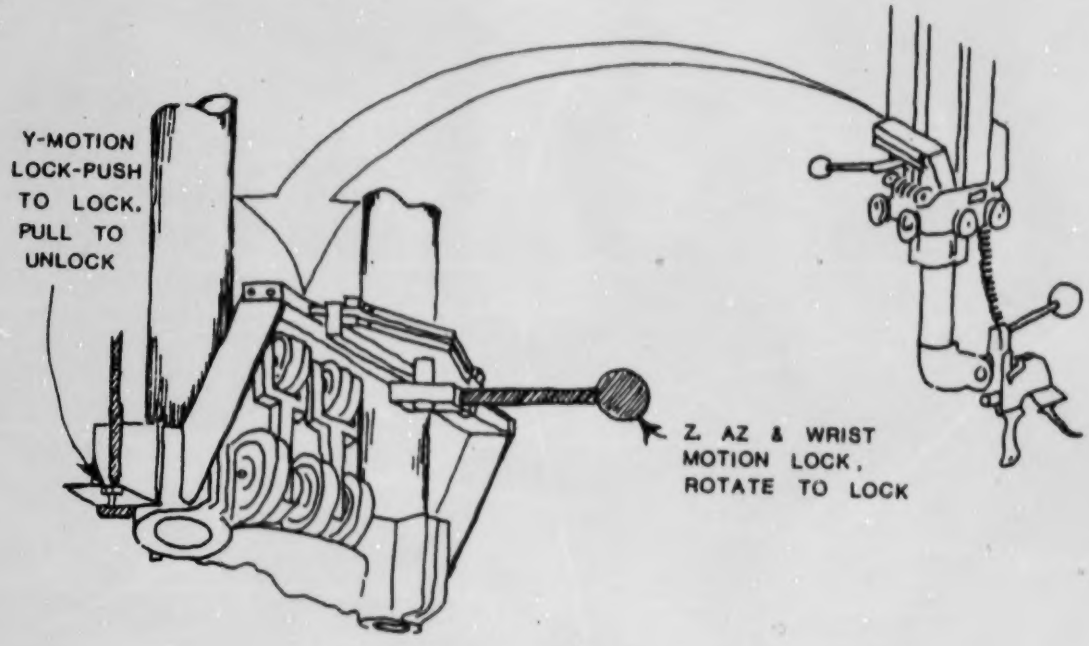


Figure 25-4-10. Motion locks.

Locks must not be released until the load is under manual control. If the load is not held manually, the sudden force exerted by a heavy object will cause the slave arm to swing towards a vertical position. This force may cause the manipulator to drop a load or cause the master end to swing and possibly injure the operator.

FINGER CHANGE OPERATIONS

Manipulators sometimes are utilized with different fingers for different types of operations. Figure 25-4-11 illustrates two general types. The fingers are attached to the tong socket by a latch held in position by a detent pin (Figure 25-4-12). When this pin is depressed, the latch is released, and the finger can be removed.

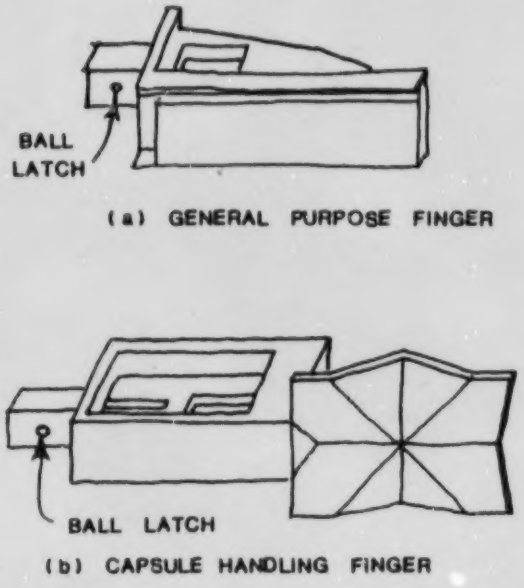


Figure 25-4-11. Two types of fingers.

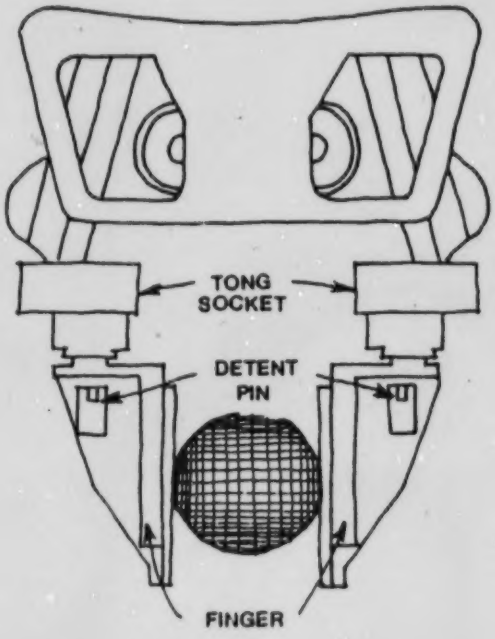


Figure 25-4-12. Detent pin/finger location.

A manipulator's fingers often are changed remotely by use of a finger-removal fixture (Figure 25-4-13).

The fingers of the manipulator are aligned in such a manner that they can be pushed upon the fixture arm. When

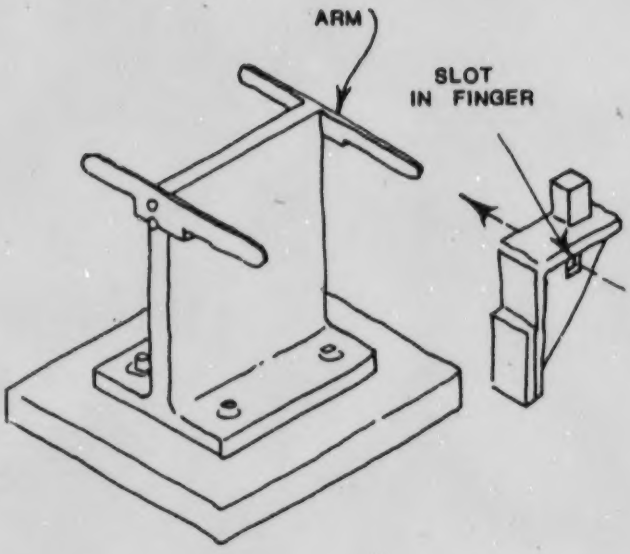


Figure 25-4-13. Finger removal fixture.

they are pushed upon the arm, the detent pin is depressed; the latch is released; and the finger can be removed.

THE BOOT

The boot (Figure 25-4-14), a pleated covering made of a plastic material, covers most of the slave end of the manipulator, except the fingers. It serves two important purposes: (1) It provides an air seal between the operating gallery and the cell and (2) protects the slave end from radioactive contamination and chemical vapors. It is a critical part of the manipulator and, probably, its most frequently and easily damaged component. Because it is plastic, it can be burned, puncture, cut, and torn – all of which are called "boot failure." There are several ways in which these failures can be avoided:

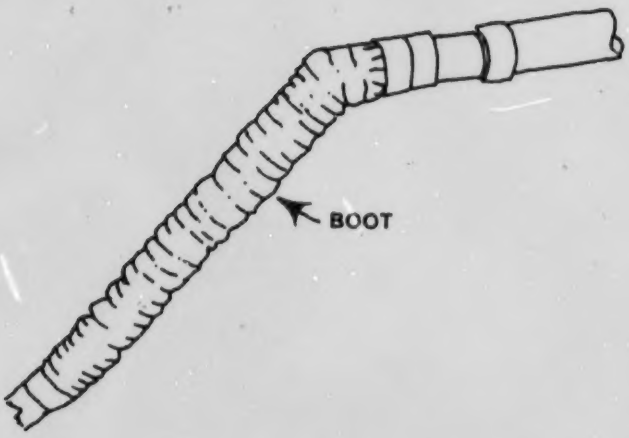


Figure 25-4-14.
Manipulator boot.

- The boot should not be allowed to touch any hot objects in the cell. ("Hot means thermally hot objects, not radioactive objects.) Most plastics have a low melting point.
- Unused manipulators should be placed in the "stored" position (Figure 25-4-15). The manipulator is positioned

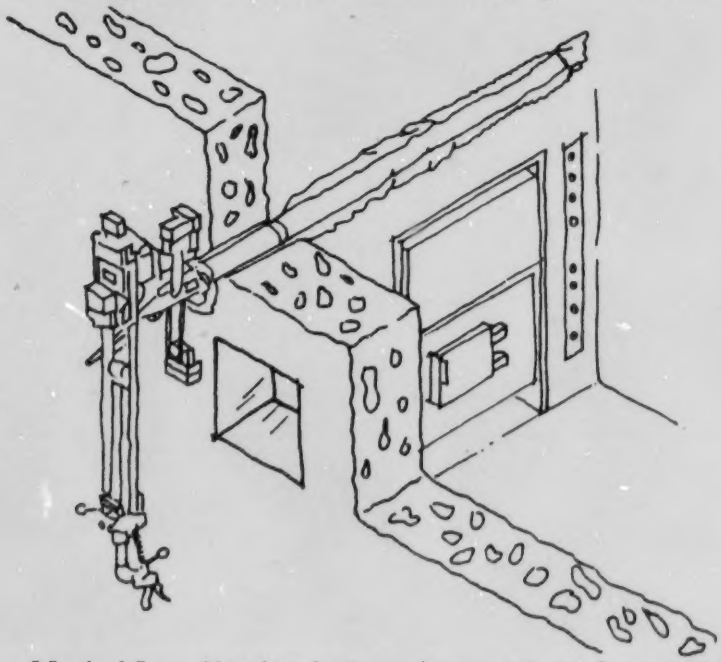


Figure 25-4-15. Manipulator in a stored position.

in such a manner that the boot is as far away as possible from source of intense radiation.

- Sharp objects should be avoided. Most tear, puncture, and cut damage occurs within two feet of the tong end of the manipulator.
- Objects should be gripped properly. Objects that are grasped too far into the fingers may puncture the boot.

The best way to detect a leak is to determine if air is being forced out of the slave end of the manipulator.

Since the pressure of the air in the cell is lower than that of the operating gallery when the boot first is installed, there is an initial air flow from the gallery into the boot. This flow inflates the boot. After this initial flow, the air in the boot will equal the operating gallery pressure, and no air will flow. When the boot is damaged, the air will begin to flow from the higher pressure gallery through the through tube and out the hole in the boot. A lightweight piece of material can detect this flow if it is placed in front of the opening of the through tube. If the air current sucks the paper against the opening, the boot is leaking. When a boot is damaged, it should be removed from the cell.

SUMMARY

To learn how a manipulator is utilized is not difficult; actual use of the manipulator to do some of the typical operations performed with radioactive materials is another story. Proficiency with the manipulator comes only through patient practice. This practice should be sequenced to begin with simple motions and only usually involve more intricate manip-

ulations (meaningful combinations of motions). There sometimes is a tendency to proceed too quickly. This should be avoided, For most persons, progress necessarily must be slow. Each step must be mastered before the next step is attempted. Caution should be exercised at every step. The special precautions mentioned in Modules 25-3 and 25-4 are outlined below. They should be remembered.

- Watch out for sharp and hot objects. A manipulator's boot can be damaged easily.
- Grasp and push an object properly. Grasp an object above its center of gravity, making sure it is not too far back in the tongs. Push with the tong fingers aligned in the direction of the push force.
- Remember the mechanical limits of the manipulator. Don't apply excess pressure against the twist stops. Lift properly, and avoid placing excess stress on the wrist yoke. Lift heavy weights from the vertical position. Don't let the speed control exceed the 3/4 limit.
- Use only the tong force necessary to handle an object.
- Do not release the motion locks unless holding loads are under manual control.
- Place the index controller in the OFF position when a movement has been completed.

EXERCISES

Assume that the manipulator is in the "stored" position (Figure 25-4-16). Write a step-by-step procedure for performing each of the following operations.

1. Finger removal.
2. Installing threaded lid (object A) on a 5-centimeter by 15-centimeter object (object B), placing the pipe behind a door (C), and closing the door.
3. Positioning the manipulator in the "stored" position.

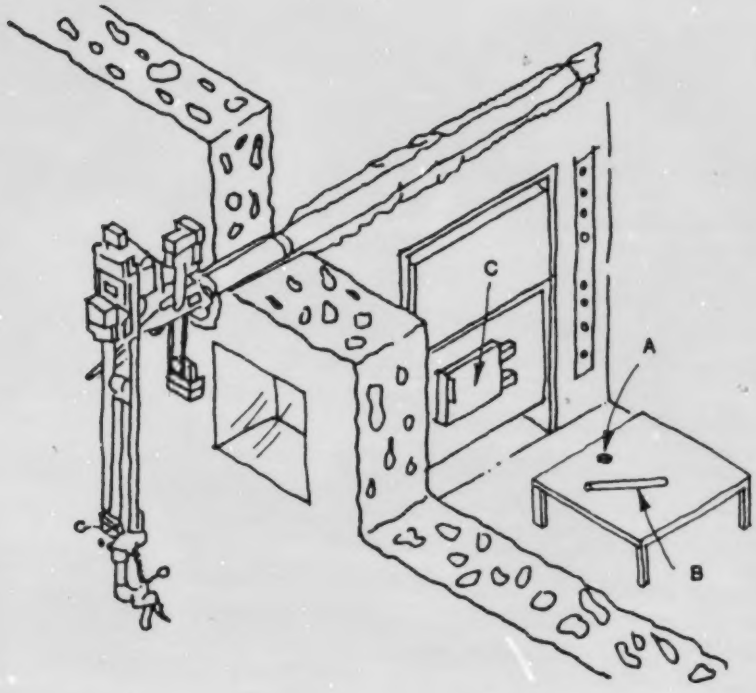


Figure 25-4-16. Manipulator in stored position.

MATERIALS

Master/slave manipulator in a mock up cell.
Finger removal fixture.
5-centimeter by 15-centimeter threaded pipe with threaded lid.
Enclosed box with door.

PROCEDURES

Use the manipulator to perform the following operations.

1. Finger removal.
2. Install the threaded lid on a 5-centimeter by 15-centimeter pipe, placing the pipe behind the door and closing the door.
3. Return the manipulator to the "stored" position.

DATA TABLE

None.

Central Research Laboratories. Master-Slave Manipulators. Red Wing, MN: Central Research Laboratories.

1. List the three indexing motions, and write a definition for each of them.

2. Use Figure 25-4-17 as a reference, and write a brief explanation of how the three indexing motions are activated, how motion speed is controlled, and how motion direction is selected.

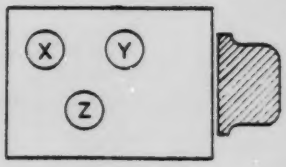
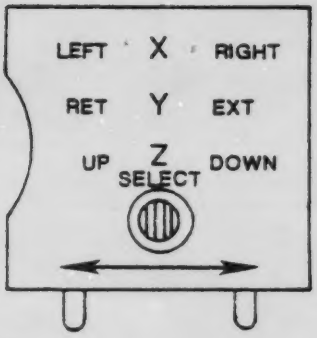


Figure 25-4-17.



3. Match the electrical indexing motions on the left with the appropriate description of their mechanical limitations on the right by placing the correct letter in the parentheses.

a. X motion ( )
b. Y motion ( )
c. Z motion ( )

A. Extends the slave boom beyond the manual limits of the manipulator.
B. Elevates the slave arm 90°; retracts it 20°.
C. Moves the slave arm 20° left or right of the master arm position.
D. Retracts the slave arm 40°; elevates it 90°.

4. In Figure 25-4-18, label the Y and the Z, AZ, and WRIST motion locks. Describe how they are activated.

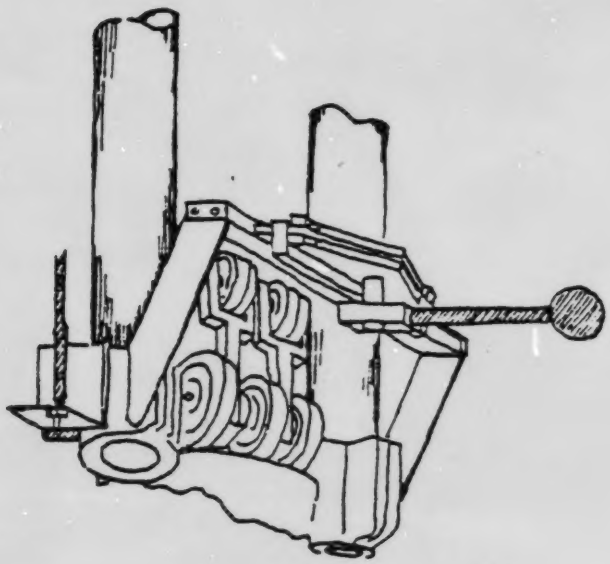


Figure 25-4-18.

5. List two purposes served by the manipulator boot.

6. List three causes of common boot failure.

7. Describe boot leak.

8. List two ways boot leak can be detected.

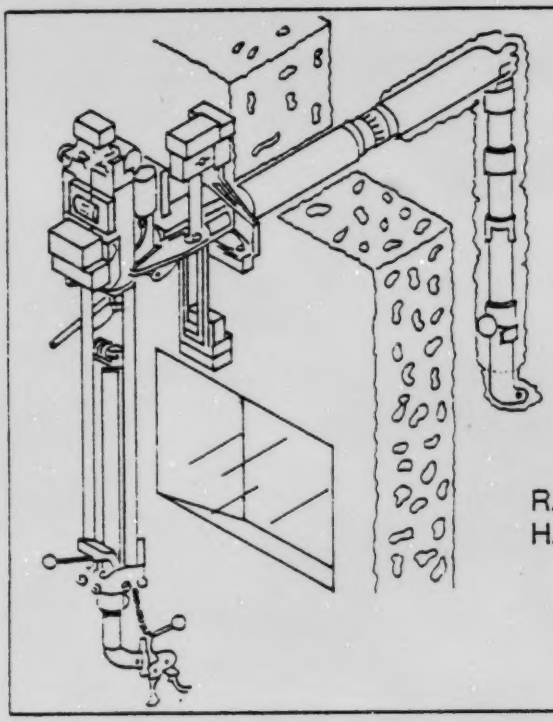
9. List two precautions which should be taken to protect the boot during and after manipulator operation.

10. Write one precaution that should be taken to protect the boot after manipulator operation.

NUCLEAR TECH

MODULE 25 - 5

REMOTE SAMPLING TECHNIQUES



RADIOACTIVE MATERIAL HANDLING TECHNIQUES

COURSE 25

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

Radioactive materials often must be sampled remotely; that is, under conditions in which the person who collects the sample is at some distance from the material to be sampled. Collection techniques and procedures must be used to ensure that the sample is, indeed, representative of the material. The procedures and techniques presented in this module serve to intorduce the complex problems and requirements of various kinds of remote sampling programs.

MODULE PREREQUISITES

The student should have completed Course 2, "Radiation Protection I"; Course 11, "Radiation Detection and Measurement"; and Course 20, "Radiation Monitoring Techniques."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List two reasons why remote sampling systems are necessary for radioactive materials.
2. Sketch and explain the operation of an air-lift system.
3. List the major requirements of a sampling system.
4. Describe at least two solid sampling techniques.
5. Describe the operation of a molten material sampler.
6. List two types of liquid samplers.
7. List three types of solid samplers.

The safe and reliable operation of a radiochemical processing facility depends upon the analysis of representative samples that have been withdrawn from vessels or pipe lines in the system. The results of these analyses are necessary if the processes are to be monitored and controlled. In most industrial processing facilities, poor sampling or analytical techniques simply would result in degradation of the product. Such poor procedures in a radiochemical processing facility could result, not only in product degradation, but also in loss of valuable material, licensing violations, violation of the Nuclear Safety Operating Permit, and loss of time. These poor procedures could cause a release of radioactive materials and accidental radiation doses.

Sampling techniques are fairly well standardized throughout the industry. Although they may appear burdensome to the inexperienced, they have been developed through considerable experience with the systems involved. However, the procedures can be improved. Development of new hardware always leads to changes in techniques.

SAMPLING REQUIREMENTS

HOMOGENEOUS MATERIALS

The accurate assay of materials in a container depends upon the sample analyzed. Accuracy in assay, then, requires that steps be taken to ensure that the sample to be analyzed is representative of the contents of the container. For this reason, solutions to be sampled should be mixed thoroughly

just prior to sampling. Mixing usually is accomplished by operation of a mixing device for some specified period of time prior to removal of the sample. Such mixing devices usually are air spargers, agitators, or recirculating pumps. Figure 25-5-1 illustrates examples of these devices.

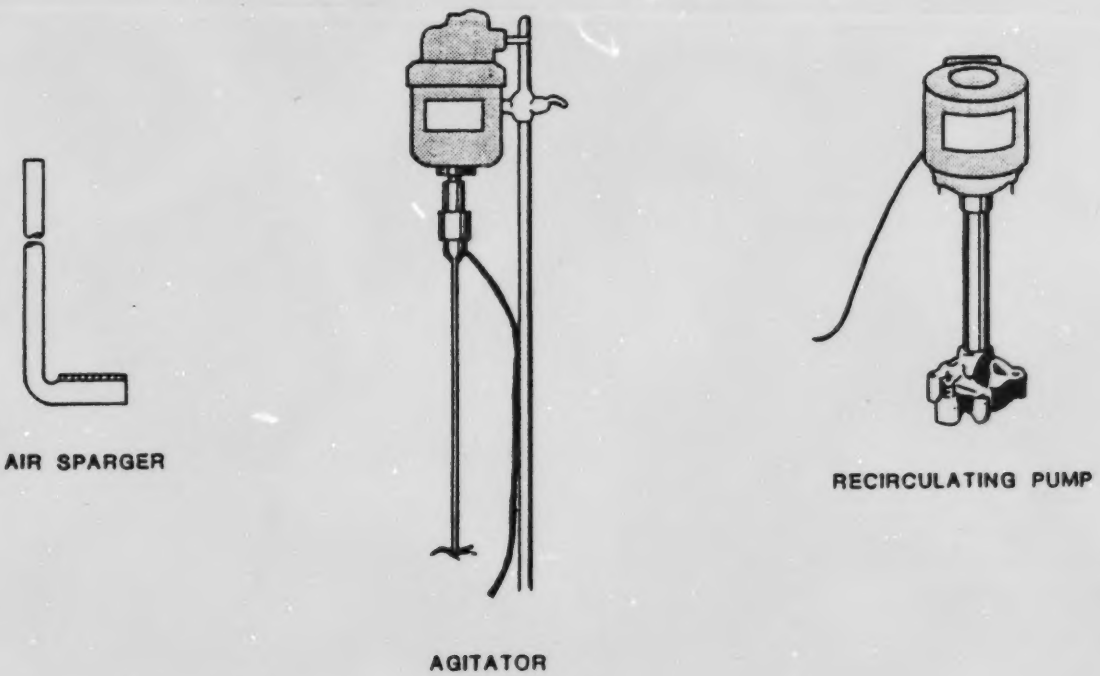


Figure 25-5-1. Agitating and mixing devices.

Tests are performed when these devices are installed to determine mixing times under varied conditions; and a detailed written procedure is developed that, when properly followed, will ensure correct mixing prior to the collection of the sample.

Solids, quite often cannot be mixed just prior to sampling. In this case, the nonhomogeneity of the material is recognized, and several samples of the material must

be obtained from various points. These samples then are analyzed, and the results are averaged or propotioned to determine the contents of the original material.

RECIRCULATION OF LIQUIDS

Erroneous results often are caused by failure to wash the sampling container after a previous sample has been collected. Even traces of a flushing solution left in the sampler may result in the dilution of a subsequent sample and may produce an error in the analysis.

To ensure that the sample is not diluted by a flushing solution, large volumes of the solution to be sampled can be circulated through the sampling system and the sample container prior to collection of the sample for analysis. Most recirculating sampling systems incorporate a bypass arrangement whereby as much as 90% of sampled solution bypasses the sampling vial, thereby adequately flushing the lengthy pipe required to transport the sample to and from the mother liquor.

HOMOGENEITY OF SOLIDS

The sampling of solids presents a unique problem because solids are difficult to recirculate. Reasonably uniform powders, such as PuO_2 or UO_2, are mixed by the batch in large blenders designed to prevent a nuclear excursion. Samples then are removed as the batch is drained from the blender. Five samples usually are taken from each batch. Frequently, one is taken from the withdrawal stream during

the beginning of withdrawal, and samples are taken as each one-fourth of the material is withdrawn.

There are some cases in which the material is not withdrawn from the mixing vessel; for example, material contained in a fluoridation vessel. Here the sampling techniques are determined experimentally, with a knowledge of sample requirements and realization that the material is not homogeneous.

PREVENTION OF SAMPLE CONTAMINATION

One of the most important aspects of sampling is the care and control necessary to prevent contamination of the sample by the sampling process. Operators usually have little control over the construction of the sampling system, which usually is constructed of stainless steel or some other material that will not corrode on contact with the material being sampled. The prime source of contamination, then, is the sampling vial itself, which the operator can control.

Sampling vials normally are processed through a washing and drying operation prior to use, in order to remove all external contamination. However, the vials should be inspected before collection of the sample to ensure that they are clean and dry. Additionally, when hygroscopic materials are to be sampled, it may be necessary to withdraw the sample in an inert, moisture-free atmosphere in order to prevent contamination of the sample.

DRY-JET SAMPLERS

The dry-jet liquid sampler derives its name from the fact that the liquid to be sampled does not flow through the sampling container. An example of this type of sampler is the one designed and installed in the Oak Ridge National Laboratory (ORNL) THOREX (thorium-uranium 233 separation) Pilot Plant. Figure 25-5-2 is a simplified diagram that illustrates the operating principle of this sampler.

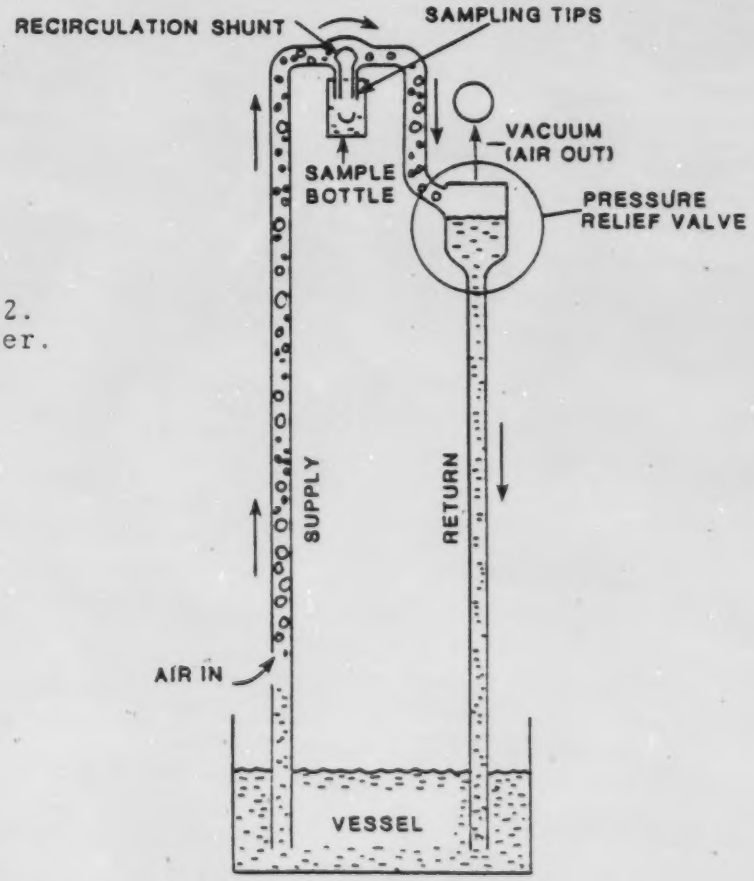


Figure 25-5-2.
THOREX sampler.

An installation sketch is provided in Figure 25-5-3. The design features of interest are –

- Use of a dry jet.
- Liquid-gas shunt around the needle tips.
- Control of the air supply to both the jet and the air lift by a single valve.
- Combination air separator, pressure-relief valve (PRV), an enlarged version of which is depicted in Figure 25-5-4.

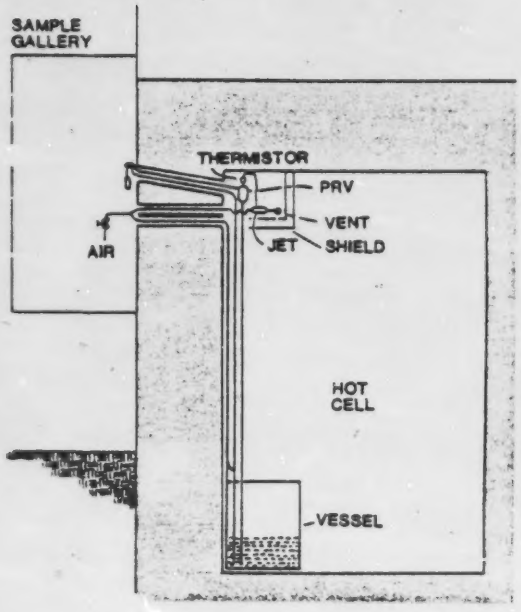


Figure 25-5-3.
Installation of the THOREX sampler.

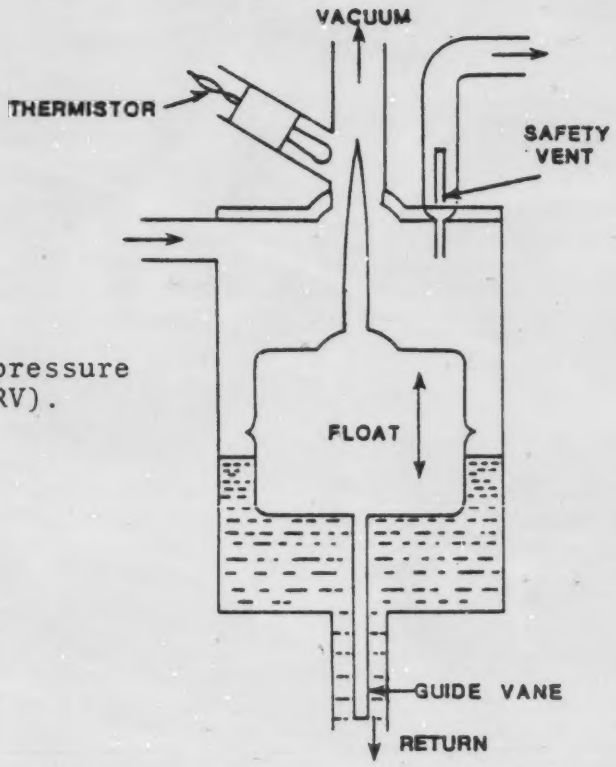


Figure 25-5-4.
THOREX sampler pressure relief valve (PRV).

Design of the PRV is crucial to successful operation of the system. Located in the liquid return line (between sampler tip and vessel) the PRV maintains the liquid level in the return line by the degree of vacuum above the liquid in the PRV chamber. The vacuum, in turn, is controlled by the position of the float in the chamber and by the tapered throttling rod, attached to the float.

Samples are collected in a penetrable-top bottle. The bottle is placed on a conveyor that carries it into the shielded enclosure of the sampler and places the bottle in position beneath the sampling tip. The bottle then is raised, the needle of the sampling tip penetrates the bottle cap, and the sample is collected. The shunt around the sampling tip provides a recirculation rate approximately nine times greater than sample delivery through the bottle,

thereby ensuring good flushing of the lines to provide a representative sample.

WET-JET SAMPLERS

Solution is transferred through the jet of the wet-jet sampler. The transfer force is provided by a gas-operated jet and is assited by an air-lift. A small quantity of air is bled into the sample line just above the liquid level of the liquid to be sampled. The wet-jet sampler can handle somewhat higher lifts than the dry-jet sampler. Figure 25-5-5 is a sketch of a wet-jet sampling system.

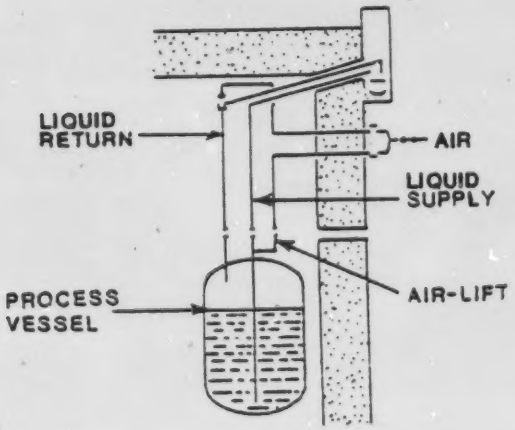


Figure 25-5-5. A wet-jet sampling system.

VACUUM PUMP SAMPLERS

Vacuum-pump samples are similar to dry-jet systems, with the exception that the motivating force is the vacuum pump. This type of system is not used as often as the wet- or dry-ject systems because regulation of the vacuum is

difficult. Vacuum-pump samplers also require considerably more maintenance than the jet systems, and maintenance may involve significant radiation exposures.

MOLTEN MATERIAL SAMPLERS

Molten materials are in the liquid phase at elevated temperatures but become solid at ambient temperatures. This makes the use of a jet or vacuum system impractical due to the possibility of the material freezing in any part of the system. The dip sampler and the vacuum-relief sampler are considered to be adequate samplers for molten materials.

The Dip Sampler

The dipping cup of the dip sampler is manufactured from a chemically-inert material that will not dissolve readily in the molten material. Using the manipulator, the technician collects the sample by dipping the cup into a still pool of the molten material, removing it, and then allowing the sample to cool and solidify, usually in the cup. After the sample has cooled, it is transported to the laboratory for analysis. When the sample to be collected is molten sodium or some other highly reactive material, the sample must be collected under an inert atmosphere.

Figure 25-5-6 is an illustration of a dipping cup sampler. Such samplers and sampling techniques have the advantage of being very flexible, or adaptable to a variety of conditions. They are useful on either dynamic or static systems.

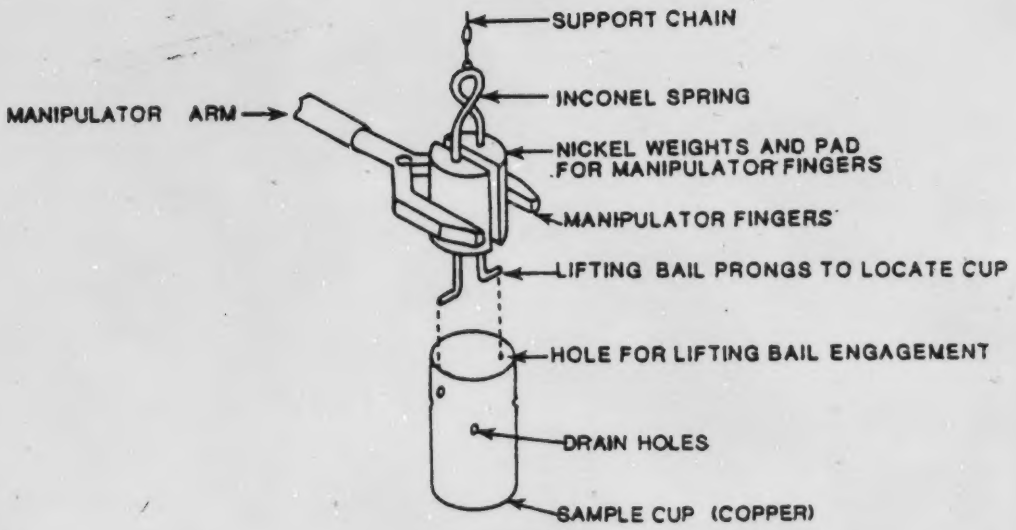


Figure 25-5-6. A hot cell dipping cup sampler for molten materials.

The major disadvantages of this sampling technique are the difficulties encountered in obtaining and protecting a representative sample. Although the sampler itself is quite simple, the manipulations required to move the sampler into and out of the process vessel are usually quite difficult.

Although collection of samples of adequate size is not difficult, precise measurement of sample size does present some problems. Additionally, segregation of sample constituents often occurs during freezing of the sample, unless there is some means by which it can be chilled rapidly.

The Vacuum Thief Sampler

A second type of sampler used for molten materials is the vacuum thief sampler, which is an evacuated tube or bulb, either glass or metal, one entrance of which is introduced below the surface of the molten material (Figure 25-5-7). A valve then is opened, and the molten material is drawn into the evacuated space; the valve is closed, and the sample is allowed to cool.

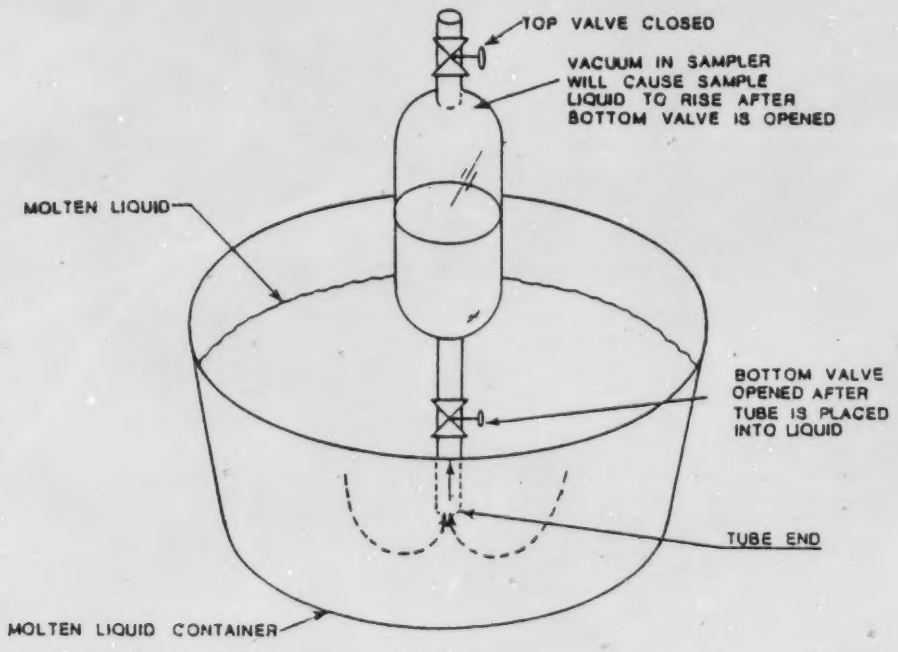

TOP VALVE CLOSED
VACUUM IN SAMPLER WILL CAUSE SAMPLE LIQUID TO RISE AFTER BOTTOM VALVE IS OPENED
MOLTEN LIQUID
BOTTOM VALVE OPENED AFTER TUBE IS PLACED INTO LIQUID
TUBE END
MOLTEN LIQUID CONTAINER

Figure 25-5-7. A vacuum thief sampler.

Two advantages of the vacuum thief sampler method are the simplicity of the sampler itself and its capability for remote operation. However, the equipment and procedures required to move the thief into and out of the sampling port may be very complex, thus adding considerably to the

problem of remote sampling. An additional advantage of this type of sampling operation is that the sample is completely contained and, therefore, is completely protected from contamination while cooling or while undergoing subsequent operations.

The sample sizing can be controlled, and samples can be obtained in rapid succession – the limitation being the time required to remove one sample container and replace it with a fresh container.

This type of sampler may be used either on a dynamic or a static system and will operate independently of any process function. Size of the sample is limited only by size of the thief, and extension of the lower sampling tube allows samples to be collected from pratically any depth.

SOLID SAMPLES

The collection of representative samples from solids presents some rather unique problems. A simple "grab sample" usually is not sufficient to be representative of the total quantity of material. Four different types of samplers have been devised for the sampling of specialized materials. Although there are many variations of these samplers, with many different operating procedures, the basic principles remain the same.

PROPORTIONAL SAMPLERS

Fuel elements for a high-temperature gas-cooled reactor (HTGR) require fuel kernels, or microspheres, coated with

several layers of carbon. Each element requires examination for coating thickness and density. Grab-tube sampling is inadequate since there is a requirement that each particle of the batch have an equal probability of being selected during sampling.

Figure 25-5-8 illustrates a sampling device developed for the HTGR fuel particles; it sorts the microspheres by gravity. This sampling procedure is based upon the standard sampling procedure of halving. A batch of microspheres is divided successively by passing the particles onto the apex of a 60° cone. The particles slide down the cone toward the base, the perimeter of which is divided into eight equal sections. Four of these sections are sampling slits, located at 90° angles to each other, and four are rejection ports, also located at 90° angles to each other. In this manner, if the entrance port for the microspheres is located over the apex of the cone, half the batch falls to the next stage, and half is rejected. The rejected particles pass through exits to a retainer bin. The remaining particles pass to the next stage, where the are directed onto the apex of the next fractioning cone.

Since the sample is halved in each stage, the number of stages determines the fraction of the material in the sample. A major advantage of this type of sampler is that it has no moving parts.

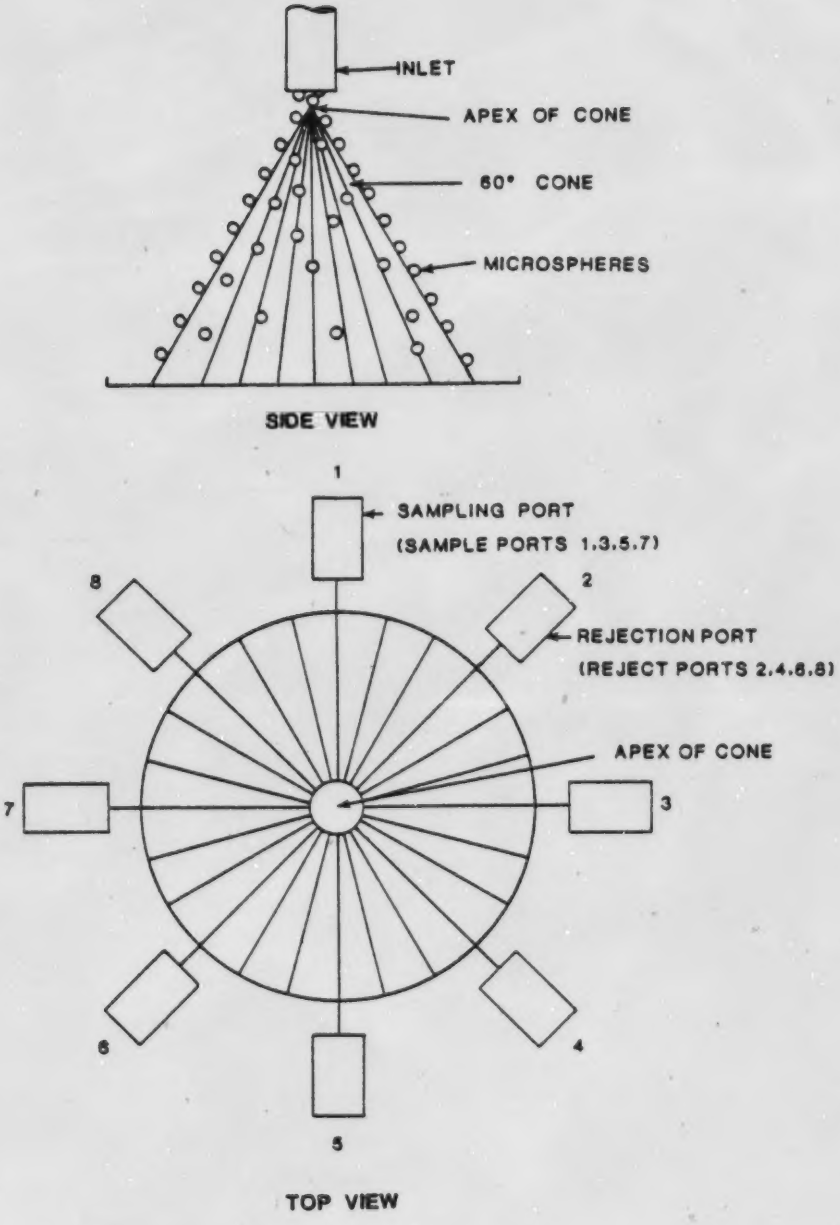


Figure 25-5-8. A proportional sampler.

CROSSCUT SAMPLING

A commercial sampler used for obtaining representative samples of solids is known as the "crosscut sampler." A variation of this sampler has been proposed for the sampling of crushed graphite fuel elements and ash for the fluidized bed burner in the HTGR program. Figure 25-5-9 illustrates this sampler, which uses a hollow blade, moving in a flat arc across a falling stream of material, a portion of which then falls down the hollow blade to a discharge tube. The speed and frequency of the blade sweeping across the material may be varied, allowing flexibility of sample size.

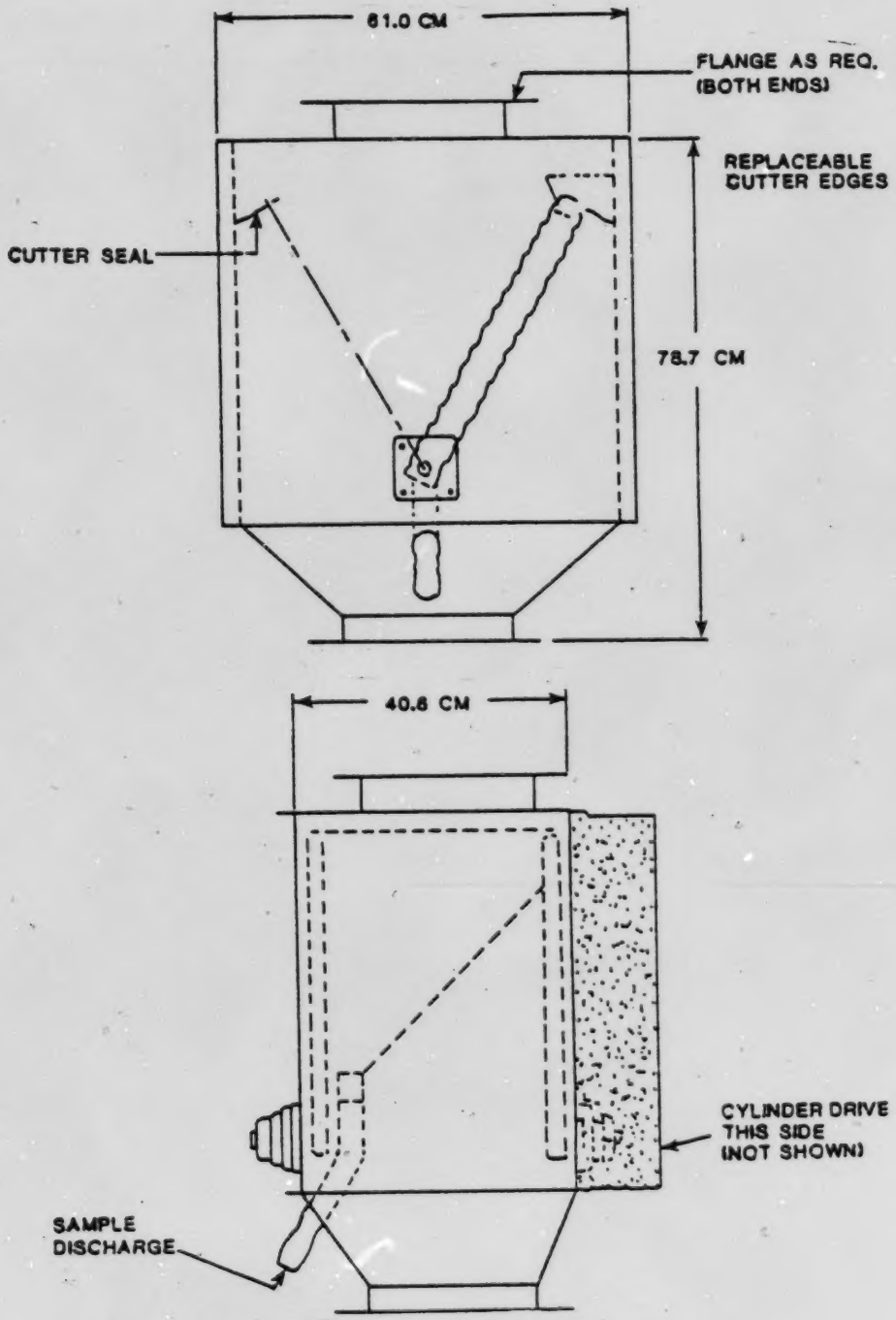


Figure 25-5-9. A crosscut sampler.

TUBE AND SCREW

A third type of sampler for solid material is the tube and screw sampling device (Figure 25-5-10). The device operates on the principle of intercepting a small fraction of a flowing stream of material and transporting a sample of the material to a sample vial. The speed of the screw can be adjusted in relation to the flow of material across it to remove the desired sample size.

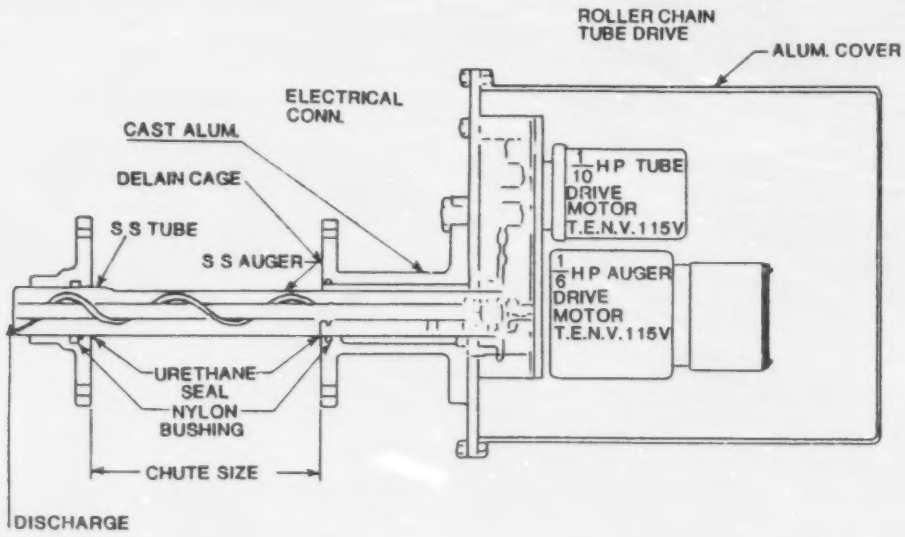


Figure 25-5-10. Diagram of a tube and screw sampler.

RETRACTABLE-TUBE SAMPLING

Still another type of sampling device is the retractable-tube sampler. An example of this type sampler is illustrated

in Figure 25-5-11. This type of sampler is somewhat similar to the tube and screw sampler in that it removes a fraction of the solids that are passed across it. The retractable tube is extended to remove a volume of solids and then is withdrawn and rotated to deposit the sample into a vial or collector. The individual sample volume and the frequency of the extension-retraction cycle determine the total sample quantity.

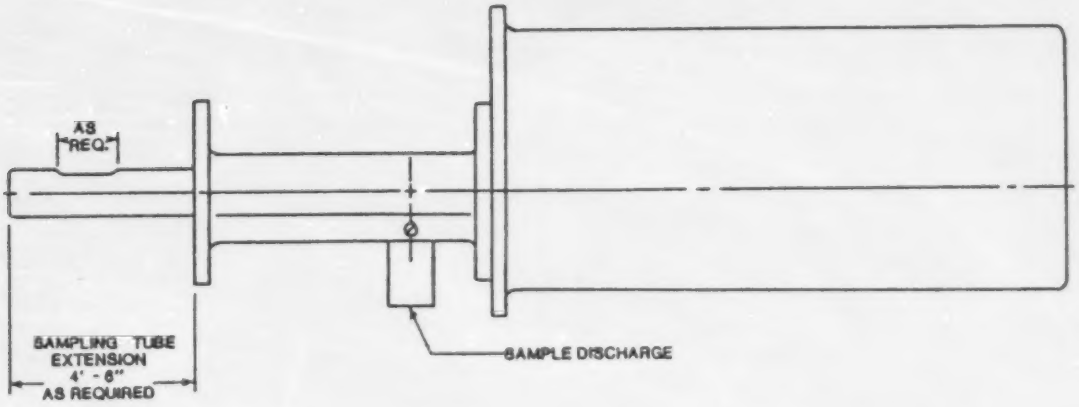


Figure 25-5-11. Retractable-tube sampler.

GAS SAMPLING

Gas samplers are designed to withdraw a sample of gas from a moving gas stream or from a container or room. Samples thus obtained then are analyzed for specific gaseous components and for the particulate content of the gas. A specific gaseous component such as tritium, iodine, or radon can be monitored by collection on some media. The media may be activated charcoal, filter paper, or some other material. The media then is counted for activity.

One method of gas sampling consists of flowing the gas stream through a collection bottle until the bottle is purged, and then trapping the sample. A typical gas sampling bottle of this type, with upper and lower valves, is depicted in Figure 25-5-12. This type of container also can be used as a vacuum thief sampler.

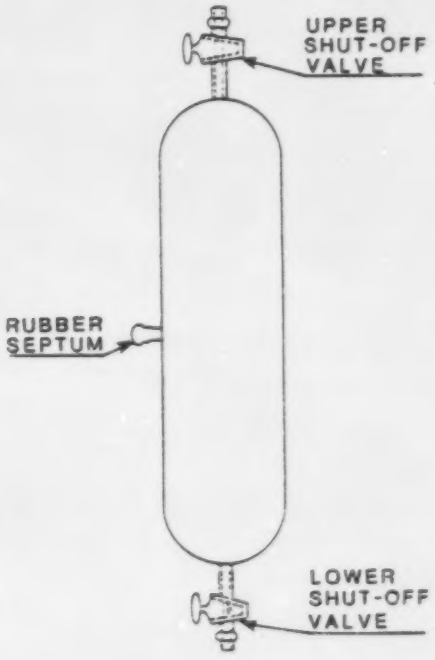


Figure 25-5-12.
A gas sampling bottle.

Figure 25-5-13 is a schematic representation of a reactor gas effluent sampler. This system accomplishes gaseous and particulate sampling at the same time. The sample is collected isokinetically; that is, the velocity of the gas entering the sampling probe is identical to the velocity of the gas stream being sampled.

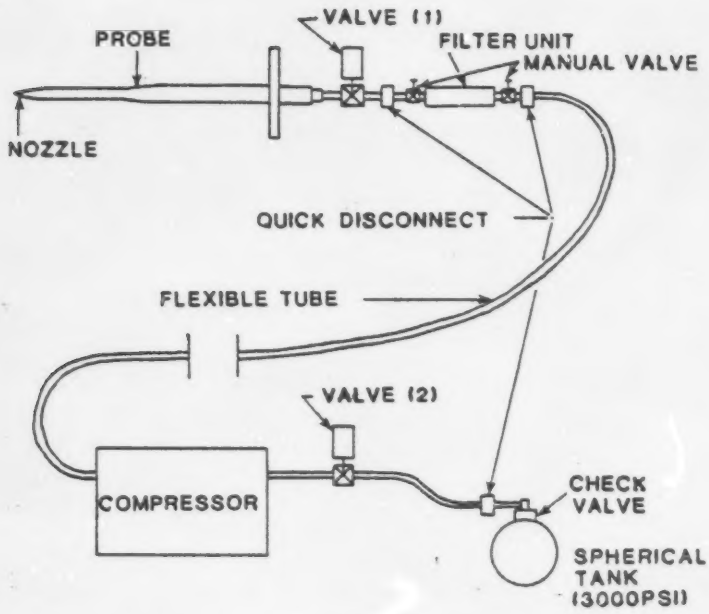


Figure 25-5-13. Schematic of an effluent gas sampler.

The sample is compressed into a container designed to hold a pressure of 3000 psig. The inside walls of the container are plated with zinc to allow removal of any of the sample that adheres to the walls of the container. (Some of the zinc is dissolved to remove the adhering sample.) The container is connected to the compressor with high-pressure flexible tubing equipped with quick-disconnect couplings for easy removal. A check valve, located between the disconnect and the container, closes when the disconnect is uncoupled, preventing release of the sample.

A schematic diagram of a typical gas sampling installation is presented in Figure 25-5-14. Both radioactive and nonradioactive gases are sampled directly into evacuated bottles. Before gas samples are collected, the process

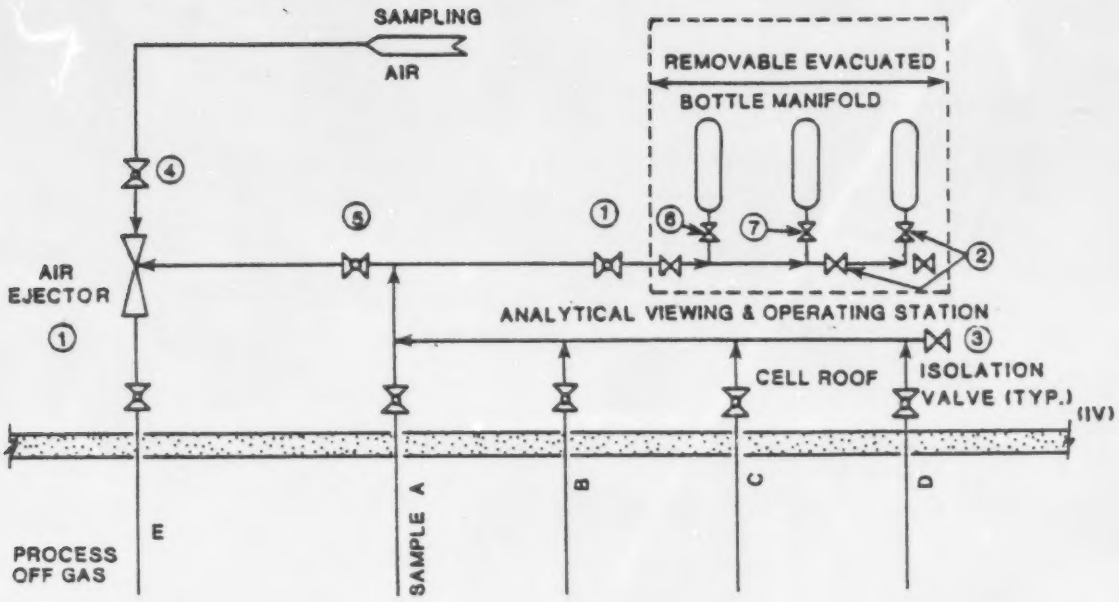


Figure 25-5-14. Schematic representation of a gas sampling station.

gas is circulated by an air ejector from the sample point to the process off-gas system. This procedure purges the lines of material left from previous sampling. While the lines are being purged, a previously-evacuated three-bottle manifold is attached to the sampling line. After the sampling lines are sufficiently purged, the sampling branch line and manifold lines are purged into the collection bottle farthest from the sampling line connection. This bottle is intended for system purging only, and its contents is not analyzed. Duplicate samples are collected in the remaining two bottles, and the bottle valves are closed. The manifold is disconnected, and the air ejector is turned off. The samples then are transported to the laboratory

for analysis. Provisions are available for the heating of the collection bottles to prevent condensation in them during collection or transportation.

EXERCISES

1. Write a description of the operation of a wet-jet sampler.
2. Describe operation of a dry material sampler that operates on the principle of halving.
3. Describe the vacuum thief technique of sampling molten materials.
4. List two types of gaseous samplers.

MATERIALS

1 N hydrochloric acid.
1 N sodium hydroxide.
Beakers, 500 and 250 ml.
Air sparger and air supply.
Burette.
pH meter.
Volumetric pipettes, 10 ml.
Magnetic stirrer.
Timer.
Linear graph paper.

NOTE: The purpose of this procedure is to observe that chemical mixing requires a finite amount of time.

1. Place 200 ml of distilled water into a 250-ml beaker.
2. Place 200 ml of 1.0 N HCl into a 500-ml beaker.
3. Place air sparger into beaker with the HCl.
4. Arrange a series of 250-ml beakers with 10-ml volumetric pipettes beside them.
5. Take a 10-ml sample of HCl solution from the 500-ml beaker; place it into the first of the series of beakers.
6. Pour the 200 ml of distilled water into the HCl in the 500-ml beaker; start air sparger and timer.
7. Remove a 10-ml sample from the 500-ml beaker every 15 seconds; place each sample into a clean 250-ml beaker. Continue this for $2\frac{1}{2}$ minutes.
8. Titrate each of the samples with 1.0 N NaOH; calculate normality of each sample, using the formula –

$$V_a \times N_a = V_b \times N_b$$

where:

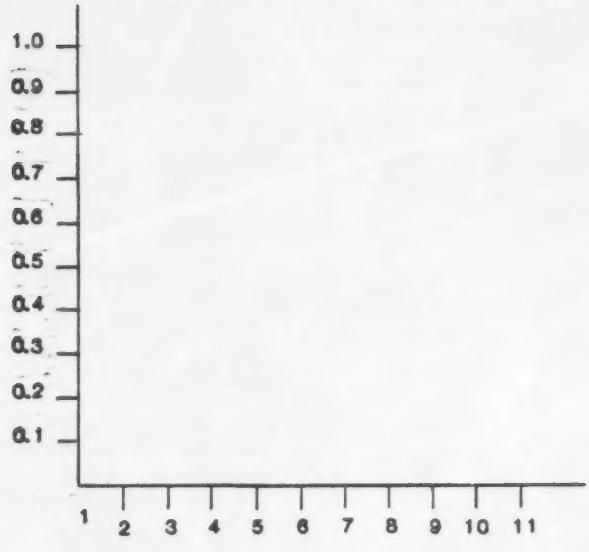
V_a = volume of acid sample.
N_a = normality of acid sample.
V_b = volume of sodium hydroxide used.
N_b = normality of sodium hydroxide.

9. Normality of the acid solution should approach 0.5 N at some point. Record data in Data Table 25-5-1. Prepare a plot of acid sample normality versus sample number, using linear graph paper; transfer graph to Data Table 25-5-2.

DATA TABLE 25-5-1. ACID MIXING.

Sample	Normality
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

DATA TABLE 25-5-2.



A.S.T.M. 1978 Annual Book of ASTM Standards, Part 12, Chemical Analysis of Metals; Sampling and Analysis of Metal Bearing Ores. Philadelphia, PA: American Society for Testing and Materials, 1978.

_____. 1979 Annual Book of ASTM Standards, Part 41, General Test Methods, Nonmetal; Statistical Methods; Space Simulation; Particle Size Measurement; Laboratory Apparatus; Durability of Nonmetallic Materials; Metric Practice. Philadelphia, PA: American Society for Testing and Materials, 1979.

_____. 1978 Annual Book of ASTM Standards, Part 45, Nuclear Standards. Philadelphia, PA: American Society for Testing and Materials, 1978.

1. List at least two reasons why remote sampling systems are necessary for radioactive materials.

2. Sketch and describe operation of a dry-jet sampler.

3. Sketch and describe operation of a wet-jet sampler.

4. List major requirements of a sampling system.

5. Describe operation of a vacuum thief sampler for molten materials.

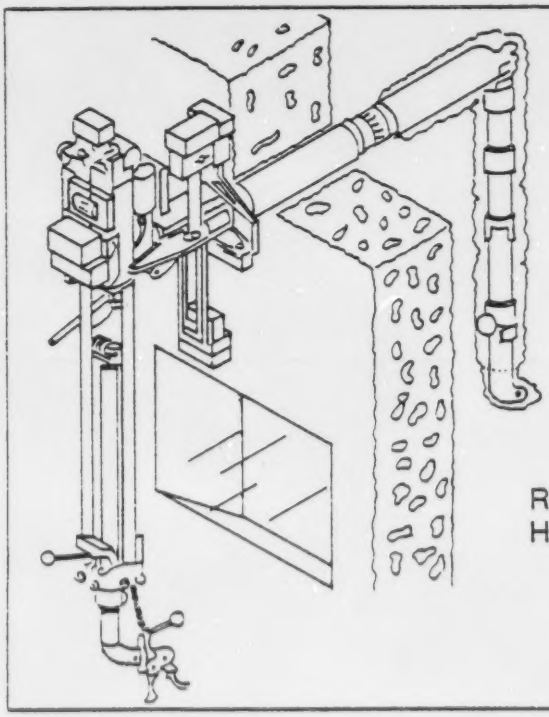
6. List three types of solid samplers.

7. Describe a solid sampling system based upon the principle of halving.

NUCLEAR TECHNOLOGY

MODULE 25-6

RADIOACTIVE WASTE DISPOSAL PROCEDURES



RADIOACTIVE MATERIAL HANDLING TECHNIQUES

COURSE 25

ORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

Radioactive wastes are generated in practically every phase of the nuclear industry, from uranium mining to the use of specific isotopes in research, industry, and medicine. The quantity, activity, and toxicity of these radioactive wastes vary over a wide range. Wastes consist of solids, liquids, or gases, or any combination of these physical forms.

Regulations of the Nuclear Regulatory Commission and the user's license specify waste type, amount, and method of disposal. General methods of disposal are (1) dilution of gas or liquid waste in large volumes of air or water, (2) controlled storage of solid or liquid waste in limited-access areas, and (3) uncontrolled storage in the ground or sea.

Treatment of radioactive wastes varies, depending upon the type of material and the intended method of disposal. Some radioisotopes decay rapidly, and some require a rather lengthy period of time to decay to a safe level. Natural decay is the only way in which radioactivity can be removed from a radioisotope; therefore, whatever is done to a radioisotope, decay ultimately is considered to be the final method of disposal.

MODULE PREREQUISITES

The student should have completed Course 1, "Radiation Physics"; Course 2, "Radiation Protection I"; Course 11,

"Radiation Detection and Measurement"; and Course 17, "Radiation Protection II."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
   - Low-level liquid waste.
   - Intermediate-level liquid waste.
   - High-level liquid waste.
   - Low-level solid waste.
   - High-level solid waste.
   - Natural radioactivity.
   - Fission products.
   - Activation products.
   - Radioactive gases.
   - Concentration and containment.
   - Dilution and dispersion.
   - Compaction.
   - Engineered storage.
2. Identify the typical types and quantities of radioactive wastes generated at various types of nuclear facilities.
3. Summarize the regulatory requirement, and give an example of a method of compliance necessary to minimize the hazard of a waste disposal.
4. Write a procedure for waste disposal, listing specific problems involved, when given an example of a solid, liquid, or a gaseous radioactive waste.

5. Prepare a flow diagram of general methods of radioactive waste handling and treatment.

THE NATURE OF RADIOACTIVE WASTES

Many different types of radioactive waste products are produced by the nuclear industry. Nuclear Regulatory Commission (NRC) licenses and regulations are specific for each of the over 900 different radioisotopes. Waste products containing these radioisotopes may be soluble or insoluble solids, liquids, or gases; may decay rapidly or slowly; and may give off different types of radiations at various energy levels. Thus, the management of radioactive wastes embraces not only the usual aspects of waste management, but also almost the entire field of the atomic and nuclear sciences.

The principal hazards of radioactive wastes stem from radioactivity. The radiation usually cannot be detected by the senses, and the cumulative effects may not be evident for some time. Forunately, radioactive emanations may be detected, both quantitatively and qualitatively, with the proper instruments. The radiations may be particulate or electromagnetic. The penetration range of these radiations varies, depending upon the type and energy of the radiation; and some types of radiation require large amounts of shielding material.

Radioisotopes are not influenced by outside actions. Each radioisotope decays according to its own half-life, regardless of its chemical or physical environment. Therefore, the only method of removing radioactivity from an isotope is by allowing it to decay. All processing, storing, and use of radioisotopes must be considered as intermediate steps that lead, finally, to their disposal by decay.

RADIOACTIVITY LEVEL CLASSIFICATION

Practically all areas of the nuclear industry generate radioactive waste products, and these products accumulate as solids, liquids, or gases at various levels of radioactive intensity. Radioactive liquid wastes usually are identified as being one of three levels of activity, and solid materials normally receive only two levels of classifications.

LIQUID CLASSIFICATIONS

Low-level liquid wastes are those that have a radioactive content sufficiently low to allow discharge to the environment with reasonable dilution or relatively simple processing. This type of waste results from either the handling of low-specific-activity materials or from the handling of high-specific-activity materials in a manner that allows small quantities to escape. To be considered a low-level material, the waste must contain no more than 1,000 times the concentration considered safe for direct release into the environment. The concentration contained in the liquid then usually would be less than a microcurie of radioactive material per gallon.

Intermediate-level liquid wastes are liquids that contain too high a concentration of radioactive materials to permit release into the environment after simple dilution. These products must be treated to produce a low-level liquid waste and a high-level waste concentrate. The concentration contained in intermediate-level wastes is approximately 100

to 1,000 times greater than that of low-level material. Such liquids may contain up to 1 curie of radioactivity per gallon.

High-level liquid wastes are those that require special isolation from the environment. High-level liquid wastes contain more than 1 curie of radioactivity per gallon of liquid and may contain up to several thousand curies per gallon. The principal source of high-level liquid waste is the effluent produced by the chemical reprocessing of irradiated nuclear fuel elements. The NRC defines high-level liquid waste material in Title 10, Code of Federal Regulations, Part 50. Officially, it is the aqueous waste that results from the operation of the first-cycle solvent extraction system or the radioactive concentration equivalent, and the concentrated waste from subsequent extraction cycles or equivalent, in a facility for the reprocessing of irradiated reactor fuel. Because of this definition, all other waste, regardless of its origin, falls into the category of other than high-level and may be disposed of in a commercial land-burial facility. There is a requirement, however, that the waste be converted to a solid form for burial at a commercial radioactive waste disposal facility. NRC regulations require that high-level wastes be buried in a federal repository. Additionally, some high-level liquids may require special cooling to prevent self-boiling.

SOLID WASTE ACTIVITY CLASSIFICATION

The application of the terms "high-level" and "low-level" to solid waste is somewhat different from the use of these terms to describe liquids because the concept of

Maximum Permissible Concentration (MPC) of radioactive materials in the environment does not apply directly to solids. At commercial burial sites, the term "low-level" alludes to the hazard potential of the buried radioactive material and indicates that there is little likelihood of the material being dispersed in the environment.

High-level solid radioactive wastes fall into two distinct categories: those in which the concentration of the radioactive materials is so great that there is a heat dissipation problem, and those that do not have a heat problem. High-heat, high-level solid wastes usually require external cooling in order to prevent their melting and/or burning. Low-heat wastes contain enough radionuclides to require prevention from release into the environment but are dilute enough that there are no problems with the removal of heat.

GASEOUS WASTES

Low-level gaseous wastes are, generally, those whose concentration level is considered to be safe for discharge into the environment. Anything other than low-level gaseous products is trapped either chemically or cryogenically and treated as a solid or liquid waste.

SOURCES OF RADIOACTIVE WASTE

All places at which radioactive materials are used are potential sources of radioactive wastes; however, the greatest source of radioactive waste products is the nuclear fuel cycle. This cycle includes wastes that contain natural radio-

activity as the result of mining, milling, and preparation of fuel for reactors and cores for weapons. Reactor operation and the subsequent processing of irradiated fuel elements produce wastes rich in fission products. Likewise, the irradiation of nonfuel materials in and around reactors produces additional radioactive wastes. Table 25-6-1 lists the types and sources of wastes in the nuclear fuel cycle and contains brief statements about general waste disposal methods.

Natural radioactivity refers to the radioactive materials found in nature. The natural radioactivity in the fuel cycle includes uranium, thorium, and their natural decay products. Wastes from the mining, ore milling, and fuel fabrication by use of uranium and thorium will contain uranium, thorium, radon, radium, and other naturally-occurring radioisotopes.

Most uranium mine operations are in dry formations, although some require continuous pumping of large quantities of water to keep them from flooding. This water contains only trace quantities of radioactivity and presents no significant health hazard. Recently, however, a mining method for uranium, involving the leaching of ore from a subterranean deposit by high-pressure water injection, has been used. The untreated waters from this type of operation are a health problem and must be considered a radioactive waste.

Uranium ore concentrating mills discharge liquid wastes into ponds or lagoons at the rate of 300 to 500 gallons per minute per 1,000 tons of ore processed per day. The solid residue from this operation, called "tailings," contains an insoluble form of radium.

Chemical purification of the ore concentrates is the next step in the fuel cycle and results in a "feed" prepa-

TABLE 25-6-1

TYPES AND SOURCES OF NUCLEAR FUEL CYCLE WASTES

Type of waste radioactivity	Source of waste	Form of waste	Typical isotopes	Type of radiation	Disposal methods
Natural activity	Mining of Uranium ores	Solids	Uranium-238	α,γ	Pile in open
		Liquids	Thorium-230	α,γ	Seep into ground
		Gases and dusts	Radon-222	α	Ventilate mine
	Fuel fabrication plants	Solids	Uranium-238 Uranium-235	α,γ	Decontaminate
		Liquids (acids)	Uranium-238 Uranium-235	α,γ	Neutralize, concentrate, and bury residue
		Dusts	Uranium-238 Uranium-235	α,γ	Ventilate, filter, and disperse to air
Fission-product activity	Fuel irradiation and processing	Solids (from purposeful solidification)	Strontium-90 Cesium-137	β β,γ	Encase in container and store permanently (~600 years)
		Liquids (with strontium cesium removed)	Technetium-99 Ruthenium-103 Cerium-144	β β,γ β,γ	Store in tanks for several years; then solidify in place
		Gases	Iodine-131	β,γ	React with chemicals to bind in solid, e.g., silver iodide
			Krypton-85	β,γ	Disperse to air
Activation-product activity	Reactor materials unavoidably irraidated during operation	Solids	Aluminum-28 Manganese-56	β,γ β,γ	Package and ship for land burial
		Liquids (dissolved materials)	Cobalt-58	β^+,γ	Evaporation or ion-exchange; bury residue
		Gases	Nitrogen-16	β,γ	Hold for decay (very short life) then disperse to air
	Purposeful irradiation to produce useful isotopes	Solids	Cobalt-60	β,γ	Ship for burial when no longer useful (long life)
			Phosphorus-32	β	Store for decay to safe levels (short life)

ration. "Feed" is used as uranium salt for isotope separation, or it is converted into metallic uranium or uranium oxide for fuel elements. Each ton of uranium ore processed produces approximately 1,000 gallons of low-level liquid waste.

Fabrication of fuel elements from purified uranium produces wastes of very low level, because the highly-active daughter products have been removed. Long-term storage of these materials, however, will show an increase in activity caused by a buildup of decay products. Fabrication of fuel elements also produces contaminated scrap as a waste material.

Fission products are produced when fissionable materials are irradiated with neutrons and are the largest source of radioactive waste, by far, in terms of contained radioactivity. The fission or splitting of each fissionable atom results in two new atoms called "fission products." The combined mass of these two new atoms is almost equal to that of the original atom. Fission products are radioactive and undergo one or more steps of radioactive decay before becoming stable. In some, this decay may be a matter of seconds; in others, thousands of years may be required.

Fission products are created in the nuclear fuel and remain in the fuel assemblies until they are reprocessed. Fuel assemblies of light-water reactors (LWR's) – the type in general use – are bundles of metal tubes, containing cylindrical pellets of uranium dioxide. Each pellet is approximately 1/2 inch in length, by 1/2 inch in diameter. Fissionable fuel material, as well as the fission products, thus are contained within these pellets. These fission products absorb neutrons needed in the chain reaction; therefore, they must be removed, or they would eventually

cause the chain reaction to cease. A spent fuel element still contains much valuable fissionable material, even after it has been used for a considerable time. Recovery of this fissionable material is important, along with removal of the fission products, and is an important economic aspect of the nuclear industry.

The spent fuel elements are transported to a fuel reprocessing center, where the fissionable material is reclaimed by solvent extraction. The fuel elements first are reduced mechanically to small pieces and then dissolved in nitric acid. The fissionable materials then are extracted from the solution by an organic solvent. Practically all the fission products remain in the water/acid phase. The waste material then can be collected, concentrated, and disposed of as high-level waste. Approximately 99.9 percent of the fissionable fuel may be reclaimed in this process. Each kilogram of processed fuel produces approximately 100 gallons of highly radioactive liquid. Estimates are that this process will produce 3 million gallons of waste per year by the end of the century.

Activation products are materials made radioactive by the neutron irradiation of nonfuel materials in a nuclear reactor. Structural materials are activated, as are impurities in the coolant (water, in most cases) and even in the coolant itself. Traces of iron and nickel dissolved in the coolant, for example, will become radioactive when exposed to the neutron flux of an operating reactor. These radioactive materials may be removed by ion exchange or by other methods.

RADIOACTIVE GASES

Both types of commercial nuclear power plants currently in use in the United States – the boiling-water reactor (BWR) and the pressurized-water reactor (PWR) – produce radioactive gases. Radioactive gases result from the activation of such materials as oxygen, nitrogen, and argon, and from the release of gaseous fission products such as krypton, xenon, and iodine. The fission products leak from the fuel elements into the primary reactor coolant stream. Naturally, the amount of fission products in the coolant water depends on the integrity of the fuel elements themselves. As long as the metal cladding that covers the fuel material is intact, the gas cannot escape; however, as the reactor operates, the cladding material around the fuel may develop pinhole leaks, thereby releasing some radioactive gases.

Most plants are designed to operate with fuel-element leakage of up to one percent. Such leakage then dictates the design of systems to handle the radioactive gases and to maintain discharges into the environment within the established limits.

The gases released into the primary coolant of the BWR's are carried to the turbines and condensers, along with the steam produced by boiling. The steam is condensed back to water in the condenser; but the noncondensable gases, including a small volume of radioactive gases, are vented to a cleanup system, which provides a holding time for radioactive decay. With current technology, the gases are filtered, held for a time, and then released through a stack into the environment.

PWR systems differ from BWR systems, in that most of the gases remain in the reactor coolant water in a sealed system during normal operation. The water in this system is not permitted to boil. During reactor shutdown for maintenance or refueling, the temperature and pressures are lowered, and the gases are vented to a cleanup system for containment and controlled release into the atmosphere. A small amount of gas products is discharged continuously during operation.

The gaseous products from both types of reactors are short-lived and rapidly decay to nonradioactive matter.

OTHER SOURCES OF RADIOACTIVE WASTES

Radioactive wastes also are generated by the multitude of businesses that use radioisotopes in their daily operations. Such businesses include commercial laboratories, hospitals, universities, and all types of industry. The wastes from these operations may be at almost any level of activity and may consist of any type of material. The waste from each establishment must have special consideration for handling and disposal.

MANAGEMENT OF RADIOACTIVE WASTE

The effective management of radioactive waste products includes all the steps necessary for the safe disposal of the radioactive material and the control and direction of these steps. Specific procedures are required for each

type of waste. Fortunately, two general procedures, rather broadly applied, are used throughout the industry.

The first procedure is concentration and containment, and it is used extensively. This method is popular because radioactive materials can be stored safely in controlled-access areas, but the volume of the material must be reduced to prevent unnecessary loss of space.

The second concept is dilution and dispersal. This procedure may be applied to certain low-level wastes for which dilution will reduce the activity below the permissible levels for discharge into the environment. It must be remembered that whenever radioactive materials are to be released into the environment, the amount of material is determined quantitatively for each specific isotope and that all discharges must be controlled.

Application of these broad concepts requires that each case be evaluated individually and that the results be monitored thoroughly. The continued conscientious reexamination of these procedures will assure safety and economy in the problems of radioactive waste disposal.

LIQUID WASTE TREATMENT AND DISPOSAL

CONCENTRATION AND CONTAINMENT

The concept of concentration and containment is applied to all levels of liquid radioactive wastes. The procedures used in concentration are both chemical and physical, and they apply to a variety of practices. These practices combine to produce a high-level radioactive concentrate that

is contained and a low-level effluent that may be treated further or simply diluted before discharge.

Chemical Methods

Liquid radioactive waste is treated chemically to extract material into a solvent for reclamation, for precipitation of material for concentration, for ease of separation, or for the removal of useful materials. Ion exchange, sometimes called a "filtration process," actually is a chemical method of separation. Regardless of the method, the ultimate goal of chemical treatment is the concentration of the radioactivity in a solid or sludge, leaving a relatively low-level of activity in the original liquid.

Physical Methods

Physical methods of treating radioactive liquid wastes include filtration, freezing, decantation, and evaporation. These methods frequently are in combination with some chemical treatment, but may be used independently for specific applications.

Filtration usually is employed after some chemical pretreatment. Simple filtration may be accomplished, however, through activated charcoal or some other highly adsorbent material. Filtration is very effective, particularly if the material has been flocculated (caused to form large particles) before filtration.

Freezing may be used to produce a slurry of highly radioactive material, with subsequent physical methods used

to remove the radioactive fraction, although this method has found only limited use.

Decantation is used after allowing the particulate material suspended in a liquid to settle to the bottom of a container. This method, while being less costly than filtration, requires considerably more time, unless the rate of settling can be increased chemically.

Evaporation, or distillation, is one of the most effective means of removing radioactive wastes from a liquid. In the past, however, this method normally has been limited to large treatment centers becuase of economics. Presently, there are several small packaged units for low-temperature evaporation that have become commercially available. These units are intended for the treatment of relatively small batches of low-level liquid wastes and should be of interest to small installations.

Figure 25-6-1 is a flow chart for a typical low-temperature vacuum evaporator. The radioactive liquid waste is concentrated by use of a low-temperature-high-vacuum evaporation process. After the desired concentration is achieved, the residual wastes are transferred to a storage system or to a solidification system for ultimate disposal. The radioactivity in the effluent may be expected to be up to 100,000 times less than that in the waste that feeds into the system.

The principal features of this system are:

- Low-temperature operation.
- Efficient multiple system of separators.
- Automatic purity control.
- Automatic self-cleaning during shutdown.

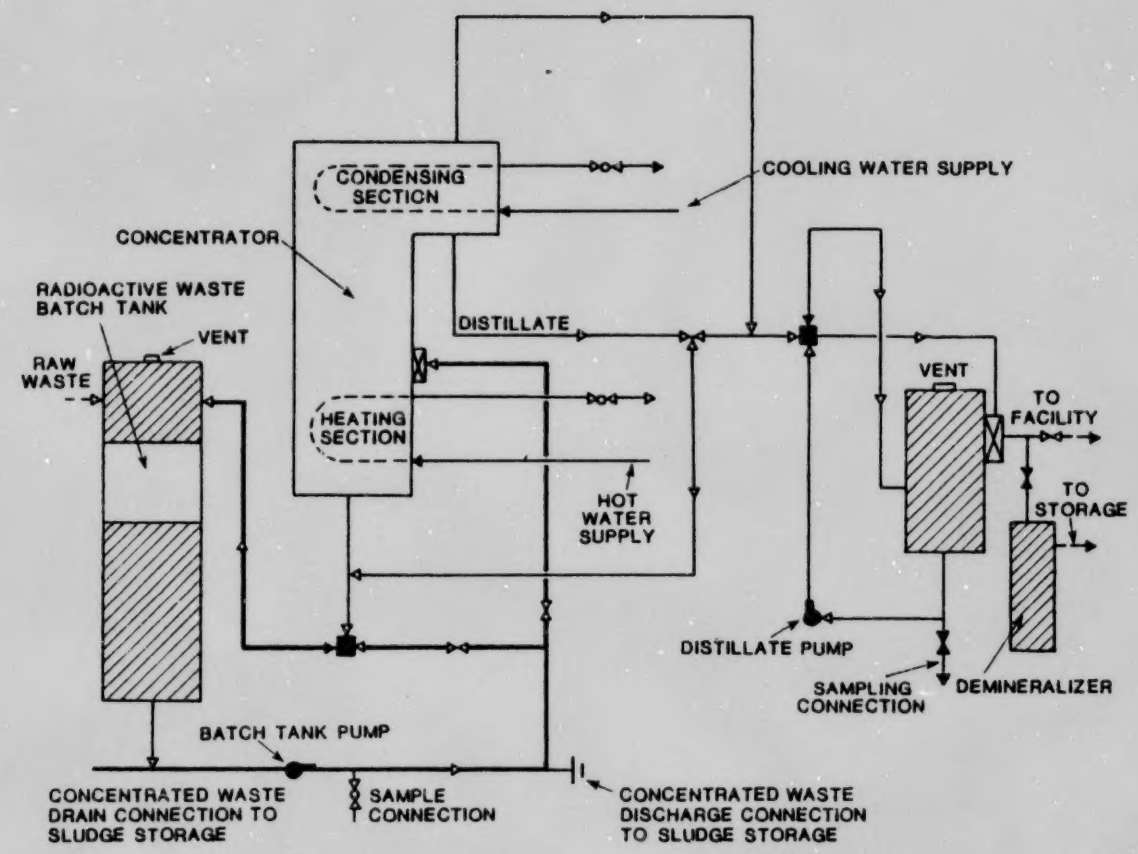


Figure 25-6-1. Low-temperature evaporation system.

Specific operations vary from unit to unit, but the fundamentals remain the same. These units are based upon the boiling of the solution at reduced pressure and temperature in order to remove the solvent. Similar units are operated throughout industry to clean and dewater petroleum products and cleaning solvents.

Solidification

The semi-solid residue from radioactive liquid waste may be treated by one of two methods. It simply may be dewatered and dried before storage, or it may be mixed with cement to form a solid. Either material usually is sealed in a steel canister before ultimate disposal.

DILUTION AND DISPERSION

Low-level liquid wastes and the effluent from the treatment of both high- and intermediate-level liquid wastes may be disposed of by dilution and dispersion. Within the United States, Title 10, Code of Federal Regulations, Part 20, spells out the requirements for discharge of any radioactive material into the environment. Regulation 10CFR20 requires that (1) the material must be readily soluble or dispersible in water; and that (2) the quantity of any licensed or other radioactive material released into the system in any one day does not exceed either (a) the quantity, which, if diluted by the average daily quantity of sewage released into the sewer by the installation, will result in an average concentration equal to the Maximum Permissible Concentration (MPC) specified in Appendix B, Table I, Column 2 of 10CFR20, or (b) ten times the quantity of such material specified in Appendix C of 10CFR20, whichever is the larger amount. Regulation 10CFR20 further specifies that the quantity of any radioactive material released in any one month, if diluted by the average monthly quantity of water released by the installation, must not

result in an average concentration exceeding the 40-hour occupational MPC's and that the gross quantity of radioactive material released into the sanitary system by the installation must not exceed 1 Ci/yr. The following examples illustrate the calculations required when disposing of radioactive waste material in the sanitary wastewater system under the above regulations. Refer to Appendices B and C of 10CFR20 to obtain the required MPC's.

EXAMPLE	
Given:	A quantity of the radioisotope ^{131}I is to be discharged into the sanitary wastewater system. Case A, wastewater discharge is 15,000 liters per day. Case B, wastewater discharge is 1,000 liters per day. ^{131}I MPC_w from Table 1, Column 2, Appendix B, 10CFR20: 6×10^{-5} µCi/ml ^{131}I MPC from Appendix C, 10CFR20: 10 µCi/ml
Find:	The quantity of ^{131}I that may be discharged under each case.
Solution:	Case A: Appendix B 6×10^{-5} µCi/ml x 10^3 ml/l x 1.5×10^4 l/d = 900 µCi/d Appendix C 10 µCi/ml x 10 = 100 µCi/d

Therefore, the installation could dispose of up to 900 µCi of ^{131}I per day.

Case B:
Appendix B
6×10^{-5} µCi/ml x 10^3 ml/l x 10^3 l/d = 60 µCi/d
Appendix C
10 µCi/d x 10 = 100 µCi/d
Under these conditions the installation could dispose of up to 100 µCi per day.

There is a further restriction, however, that the monthly discharge must not exceed the MPC_w when diluted with the average monthly flow of wastewater. The institution in Case B would be limited to 1800 µCi/month rather than the 3000 µCi that could be discharged if the installation disposed of the maximum allowed under Appendix C for Case B every day.

An additional limitation is applied when combinations of radioisotopes are involved. The limit for the combination is calculated by establishing the ratio between the amount of the isotope present and the amount permitted for that isotope alone. The sum of the ratios for all the isotopes in the combination may not exceed "1."

Regulation 10CFR20 specifically exempts the excreta from people being treated with radioisotopes for medical diagnosis or therapy from regulation. This amount of radioactivity is not used, therefore, in the calculation of discharge amounts.

TREATMENT AND DISPOSAL

Radioactive solid wastes are classified as low-level or as high-level wastes. Both classifications may receive the same general treatment before burial. These treatments are designed to reduce the total volume of the material before burial.

COMPACTION

The most favored method of volume reduction of solids has often been compaction, because of the commercial availability of reliable, easily operated equipment. This, coupled with the ease and low cost of burial of simple packages has generally diminished the economic incentives of reducing stored solid waste volumes.

The requirements for compaction must specify limitations on the material as to its composition, moisture, containment, volume, and isotopic content. Materials suitable for compaction frequently include such things as paper, cloth, rubber, plastic, wood, glass, and light-gauge metal objects. Objects that are large or solid are best excluded because they usually are not compressible. Likewise, objects with a high moisture content should be avoided because of limited compressibility or the possible spread of contamination by leakage during compression. Explosive, corrosive, and pyrophoric materials also should be avoided.

The most common compactor in use in the nuclear industry is the 55-gallon drum compactor. Such a unit can be operated either mechanically or hydraulically to produce a final product encased in a 55-gallon steel drum. Figure 25-6-2 is a representation of a high-compression drum compactor. Such compactors are covered by protective enclosures that prevent the escape of airborne particulates.

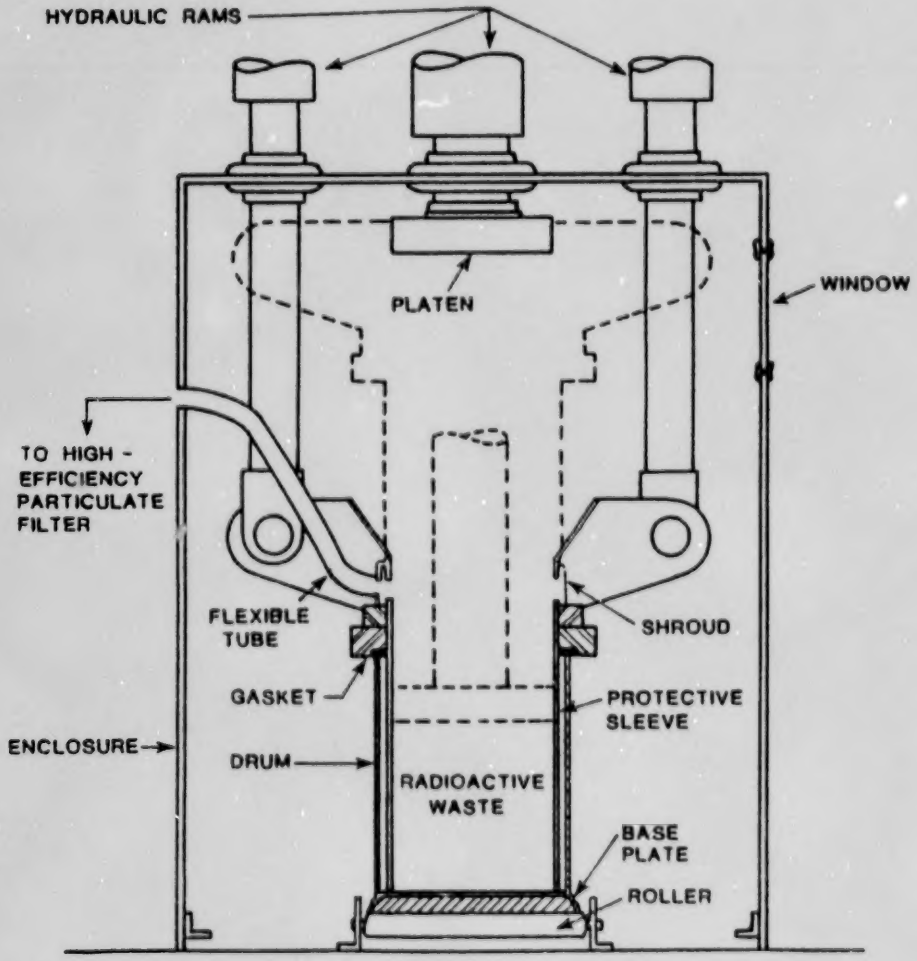


Figure 25-6-2. High-compression drum compactor.

Since the compactor presses the material directly into a drum, the waste material is contained in a final leakproof container.

INCINERATION

The use of incineration as a method of volume reduction has met only with limited success in the United States. Several systems have been tested using combustible trash contaminated with radioactive materials, but almost all of them have failed to provide the desired performance and have been too expensive to maintain. Thus far, the principal use of incineration has been in the recovery of plutonium from burnable scrap.

BURIAL

Disposal of low-level, solid, radioactive waste presently is accomplished best by near-surface land burial. The term "low-level" refers to the hazard potential of the radioactive material to be buried at a commercial burial site. Regulation 10CFR20 specifies that the waste must be in solid form and that the commercial land burial facilities must be on land owned by either a state or the Federal government. Figure 25-6-3 is a map that identifies the commercial land burial sites for low-level wastes at Federal facilities. Additionally, the Agreement discusses license facilities on state property.

Figure 25-6-3. Commercial burial sites in the United States.

High-level solid wastes presently are being handled through a concept known as "engineered storage" at repositories called "Retrievable Surface Storage Facilities." These facilities will be equipped to water-cool the storage canisters. Figure 25-6-4 is an illustration of a typical Retrievable Surface Storage Facility. The canisters to be stored at the facilities are from 1/2 foot to 2 feet in diameter and from 2 to 10 feet in length.

A typical storage canister is depicted in Figure 25-6-5. The filled canisters are shipped to the facilities in special shipping casks designed to provide both cooling and radiation shielding during transit. Figure 25-6-6 illustrates a typical shipping cask for spent fuel. The

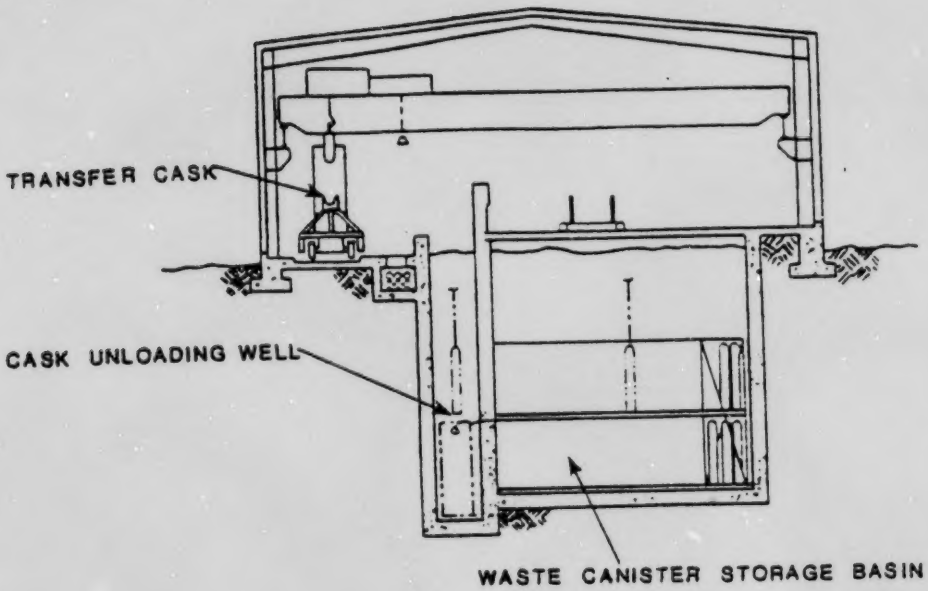


Figure 25-6-4. Retrievable surface storage facility.

	DIAMETETER	LENGTH
RANGE	6" TO 24"	2' TO 10'
TYPICAL	12"	10'

Figure 25-6-5. Typical storage canister.

larger cask can hold up to 12 canisters and when full weighs about 100 tons. Smaller casks are used to transport a single canister at a time. The amount of heat produced by each storage canister varies from 2 to 5 kilowatts; therefore, constant cooling is required.

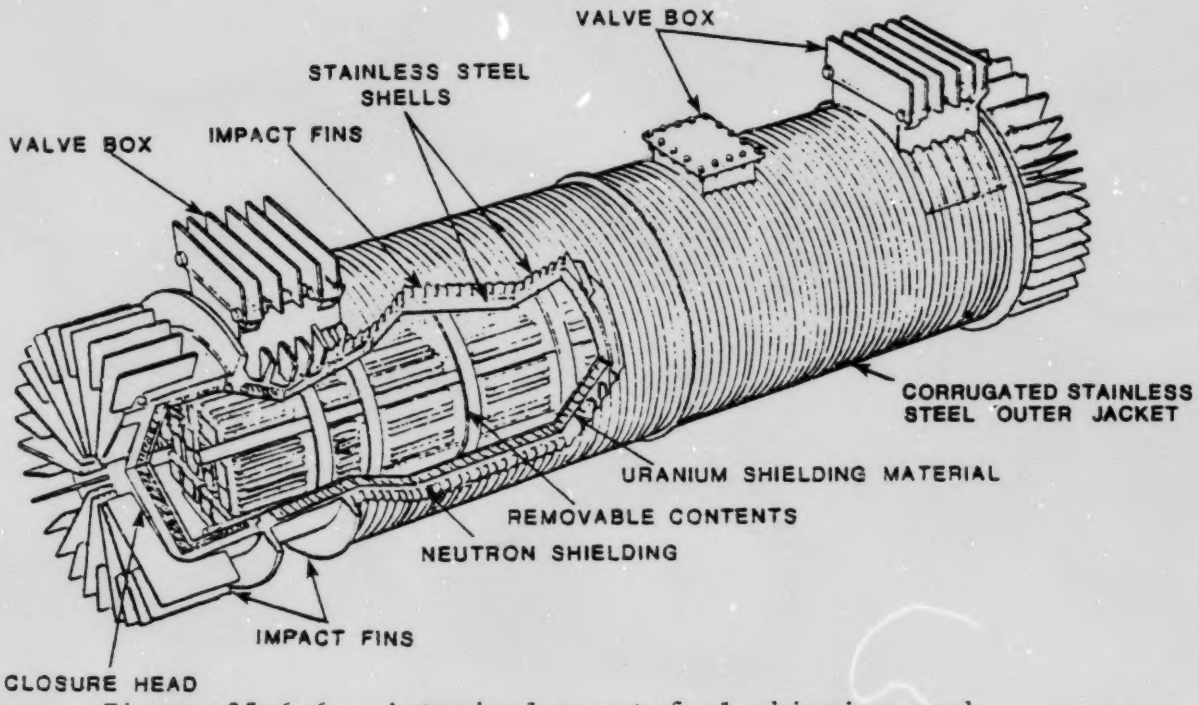


Figure 25-6-6. A typical spent-fuel shipping cask.

Salt-dome storage is another method of high-level solid-waste disposal; it involves the same procedures and canisters as already discussed. Although there are serious questions regarding the environmental impact of this approach, burial in salt domes does offer a recognizable, potential for the safe disposal of radioactive waste.

Other methods of disposal are proposed, but one promising suggestion is the utilization of the heat generated by the storage canister. Under this plan, the 2 to 5 kilowatts of heat produced by each storage canister would be used to power small generating stations to provide a source of needed energy.

TREATMENT AND DISPOSAL OF GASEOUS WASTES

Gaseous wastes, which consist of either true gases or particulate matter, require some special considerations. Specialized structures are required for the containment and treatment of these materials.

Airborne particulates may be removed by settling chambers, cyclones, impingement separators, scrubbers, or filtration devices. The residue from these types of removers can be handled as either solid or liquid wastes.

REMOVAL OF NONPARTICULATE ACTIVITY

Filtration and other methods of particulate removal are not effective in removing materials such as the radioactive noble gases, halogens, and the volatile compounds of ruthenium and polonium. Removal methods for these materials include adsorption, low-temperature trapping, and chemical reaction.

Ruthenium readily is recovered in a trap packed with iron, and iodine can be trapped in activated charcoal or on silver. Noble gases and halogens can be removed by adsorption on charcoal at low temperatures. These waste ma-

terials then can be treated as solid wastes, can be allowed to decay to stability, or can be desorbed, diluted, and dispersed into the atmosphere.

A WASTE MANAGEMENT SYSTEM

A complete waste management system includes all the procedures involved from the time the waste material is produced until it is discharged into the environment and until the environment is surveyed to assure safety. Figure 25-6-7 is a flow chart of a typical waste management system.

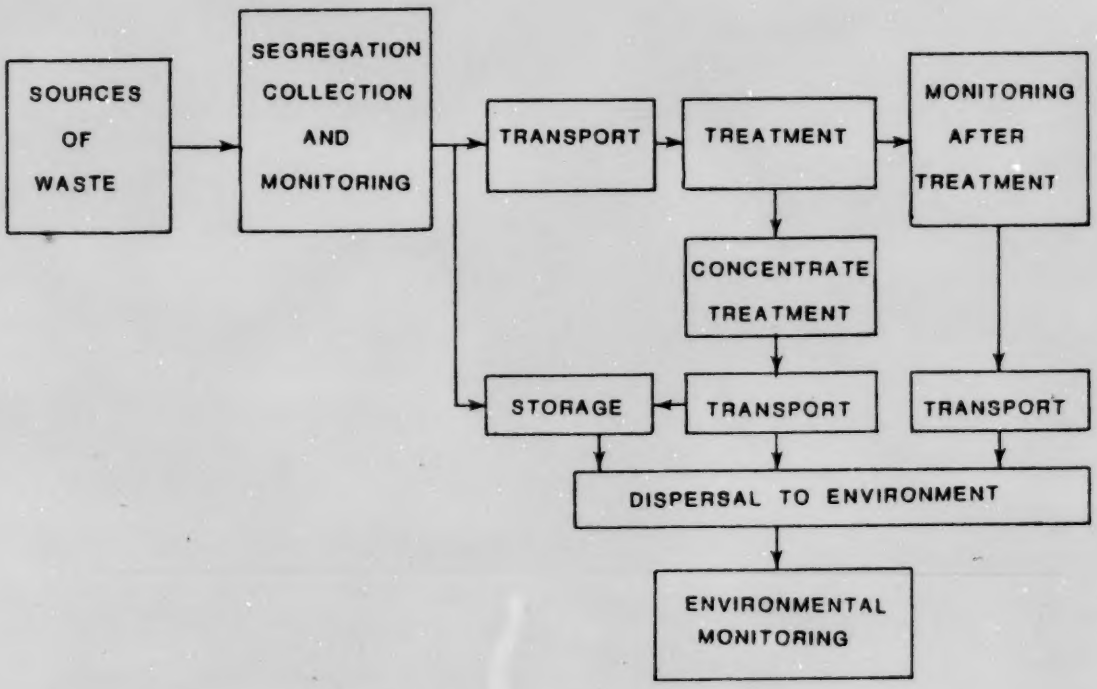


Figure 25-6-7. A typical waste management system.

This chart does not necessarily apply to all sites and operations; and for some systems, a different arrangement of the elements may be necessary, although the essential elements are present here. It is important to note the requirement for monitoring before and after treatment, and also after dispersion into the environment.

EXERCISES

1. Identify the appropriate section of 10CFR20 that limits to less than 1 curie per year the discharge of radioactive waste to a sewer system.
2. Assume a facility produced liquid low-level waste in which the ^{137}Cs concentration was 40 times higher than the ^{90}Sr concentration. This waste would be diluted enough that the resulting concentration is within legal limits. What other restrictions are placed upon this dilution and disposal into a sewer system?
3. What is the maximum quantity of Radium-226 and of Plutonium-239 allowed for disposal into a sewer system?
4. A batch of liquid waste with a total volume of 100 liters is to be disposed into a sewer system. Analysis of the material lists its contents as 10 millicuries of ^{131}I, 0.1 millicuries of ^{90}Sr, and 10 millicuries of natural thorium. The waste-water flow from the sewer system of this facility is 1,000 liters per day. How much of the liquid waste could be discharged each day?

MATERIALS

Geiger-Müeller Counter.
Uranyl nitrate.
Sodium carbonate.
Ferric chloride.
Hydrochloric acid.
Funnel.
Filter paper.
Wash bottle.
Hot plate.
400-ml beakers.
Distilled water.

PROCEDURES

SEPARATION OF URANIUM FROM ITS DECAY PRODUCTS

Explanation: Uranium can be separated from its decay products by holding the uranium in solution as a carbonate complex while coprecipitating the daughter products with ferric hydroxide.

1. Dissolve 20 grams of sodium carbonate in 200 ml of hot distilled water.
2. Add 5 grams of uranyl nitrate hexahydrate, and stir until completely dissolved.
3. Add 5 ml of 1% ferric chloride in water and stir.
4. Allow to stand for 2 minutes.
5. Filter through a loose-textured filter paper.

6. Wash the residue twice with 10-ml portions of distilled water, saving all the filtrate and washings.
7. Evaporate the filtrate and washings to dryness, being careful not to splatter contamination.
8. Dissolve the iron hydroxide residue on the filter paper by pouring 3 normal hydrochloric acid through the filter paper until all the precipitate is removed.
9. Evaporate the resulting solution to dryness.
10. Count each of these residues with the G-M counter, and count another 5-gram sample of uranyl nitrate hexahydrate. Record data in Data Table 25-6-1.
11. Discuss results.

DATA TABLE 25-6-1

Material	Sample cpm	Background cpm	Corrected cpm
Uranium filtrate			
Dissolved residue			
Unused uranyl nitrate			

REFERENCE MATERIALS

Amphlett, C. B. Treatment and Disposal of Radioactive Wastes. New York: Pergamon Press, 1961.

Gilmore, William R., ed. Radioactive Waste Disposal, Low and High Level. Park Ridge, NJ: Noyes Data Corporation, 1977.

Glueckauf, E., ed. Atomic Energy Waste, Its Nature, Uses and Disposal. New York: Wiley-Interscience, 1961.

International Atomic Energy Association (IAEA), Safety Series #19. The Management of Radioactive Wastes Produced by Radioisotope Users.

IAEA Safety Series #24. Basic Factors for the Treatment and Disposal of Radioactive Wastes.

Title 10, Code of Federal Regulations, Part 20.

1. Define the following terms:

   Low-level liquid waste.

   Intermediate-level liquid waste.

   High-level liquid waste.

   Low-level solid waste.

   High-level solid waste.

   Natural radioactivity.

   Fission products.

Activation products.

Radioactive gases.

Concentration and containment.

Dilution and dispersion.

Compaction.

Engineered storage.

2. What type of radioactive waste material might be expected from a spent reactor fuel reprocessing station?

3. Assume that a chemical purification system processes 17 tons of uranium to produce "feed." Is the liquid waste from this operation low- or high-level activity? What would be the expected volume from this operation?

4. Write a summarization of the regulations concerning the disposal of a liquid waste containing microcurie quantities of ^{131}I, ^{32}P, ^{65}Zn, and ^{124}Sb.

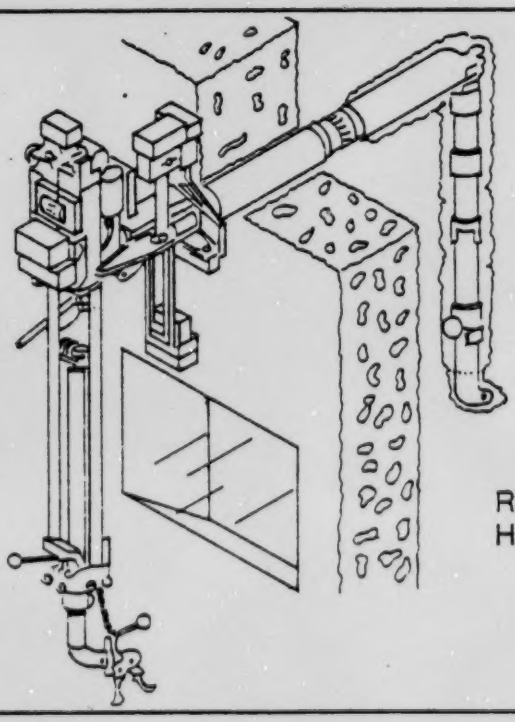
5. Write the procedure for the proper disposal of 7 millicuries of ^{210}Pb dissolved in 22 liters of water.

6. Sketch a flow diagram for the general methods of handling and treatment of radioactive waste from a source that produces solid and liquid wastes in curie quantities per day and gaseous wastes in microcurie quantities.

NUCLEAR TECHNOLOGY

MODULE 25-7

PACKAGING AND MONITORING OF RADIOACTIVE MATERIALS FOR SHIPMENT



RADIOACTIVE MATERIAL HANDLING TECHNIQUES

COURSE 25

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

The packaging and shipment of radioactive material is a complicated process. Every step is regulated, and instructions must be carried out exactly. The reference most often used is "Title 49, The Code of Federal Regulations, Parts 100 to 199." This volume contains more than 1200 closely-printed pages. It is an exhaustive listing of regulations and, unless a few shortcuts are taken, it is exhausting to use. The user must struggle through a tortuous maze of definitions, procedures, prohibitions, and rules, often emerging more confused than ever.

As with any trek through a wilderness, it is best to have a guide – someone who has been there before and has come back alive. This module is intended to be that guide. Once the right path is shown, it will be surprisingly easy to find again.

The first step is to scout ahead and establish some bearings – some landmarks to guide the journey about to begin. These "landmarks" are the definitions and explanations in these next pages. Once known, the explorer is equipped with a kind of map, and the wilderness is not the fearsome place it once was.

NOTE: The student must have a copy of 49CFR, Parts 100 to 199 in order to complete this module.

MODULE PREREQUISITES

The student should have completed Modules 25-1, 25-4, and 25-5 of this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Define the following terms:
   - Tariff.
   - Normal-Form Material.
   - Special-Form Material.
   - Transport group.
   - Fissile class.
   - Type "A" quantity.
   - Type "B" quantity.
   - Type "A" packaging.
   - Type "B" packaging.
   - Large-Quantity Material.
   - Small- or Limited-Quantity Material.
   - Low-Specific-Activity Material.
   - Transport Index.
   - Sole use.
   - Fissile classes I, II and III.
   - Stowage control.
   - Yellow-labeled package.
   - White-labeled package.
   - Shippers certification.
   - Placard.
   - Security seal.
2. Given the Transport Index of a radioactive material and a copy of Title 49CFR Parts 100 to 199, locate appropriate stowage control data for the radioactive material.

3. Given a copy of 49CFR, Parts 100 to 199 and the name, the quantity in curies, and the form of a fissile or nonfissile radioactive material, determine the following:

   Transport group of the material.
   Proper shipping name of the material.
   Hazard class of the material.
   Labels required on packages of the material.
   Paragraph references for packaging exceptions and special requirements.
   Whether material is fissile or nonfissile.
   Whether material is Type "A," Type "B," Small-Quantity, Large-Quantity, or a Low-Specific-Activity Material.

4. Given a copy of 49CFR, Parts 100 to 199, list at least three entries that must be made in the shipping papers that accompany radioactive material.

5. List the steps that must be taken when an accident causes suspected radioactive contamination while radioactive material is being transported.

REGULATORY AUTHORITIES

On January 3, 1975, the 93rd Congress passed the Transportation Safety Act of 1974 (Figure 25-7-1). This Act empowered the Secretary of Transportation to issue regulations for the safe transportation of hazardous materials. Persons who transport these materials must be registered with the federal government. The act authorized agents of the Department of Transportation (DOT) to inspect and examine the records and properties of these persons, and also provided for civil penalties to be imposed upon anybody who violates a regulation issued by the Department.

Public Law 93-633
93rd Congress, H. R. 15223
January 3, 1975

An Act

To regulate commerce by improving the protections afforded the public against risks connected with the transportation of hazardous materials, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Transportation Safety Act of 1974".

Figure 25-7-1. The Transportation Safety Act of 1974.

The DOT has regulatory responsibility for the transportation of radioactive materials (RAM). It shares this responsibility with the U. S. Postal Service and the Nuclear Regulatory Commission (NRC). The Postal Service regulates postal shipments of RAM. The NRC issues regulations for safety in the possession and use of source, by-product, and special nuclear materials. The NRC also has established requirements that must be met before a licensee can deliver RAM to the carrier for transport.

Several states have entered into agreements with the NRC whereby the NRC transfers to them regulatory authority over certain types of nuclear material. These "agreement states" have adopted regulations that control the shipment of materials from one agreement state to another. These states also control intrastate shipments. State regulations are modeled, for the most part, after federal regulations.

FEDERAL REGULATIONS

Table 25-7-1 lists the sources of federal regulations that control the transport of RAM. Title 49, Code of Federal Regulations, Parts 100 to 199 (49CFR, 100-199) is the most comprehensive. It is a codification of all the general and permanent rules of the DOT that govern the commercial transportation of hazardous materials. Changes and proposed changes to it are published daily in the Federal Register (Figure 25-7-2).

Title 10, U. S. NRC, and Title 39, U. S. Postal Service, also apply, under certain conditions, to the delivery and shipment of RAM.

TABLE 25-7-1

SOURCES OF FEDERAL REGULATIONS

Title 49	Department of Transportation's Hazardous Materials Regulations, Parts 100-199 Main Headings 49CFR170 – Rule-making Procedures of the Materials and Transportation Bureau 49CFR171 – General Information, Regulations and Definitions 49CFR172 – Hazardous Materials Table and Hazardous Materials Communications Regulations 49CFR173 – Shippers-General Requirements for Shipments and Packagings 49CFR174 – Carriage by Rail 49CFR175 – Carriage by Aircraft 49CFR176 – Carriage by Vessel 49CFR177 – Carriage by Public Highway 49CFR178 – Shipping Container Specifications 49CFR179 – Specifications for Tank Cars
Title 10	U. S. Nuclear Regulatory Commission 10CFR71 – Packaging of Radioactive Materials for Transport and Transportation of Radioactive Material Under Certain Conditions
Title 39	Postal Service, U. S. Postal Service Regulations, Part 123. (Postal Regulations for Transport of Radioactive Matter are published in U. S. Postal Service Publication #6, December, 1975, and in the U. S. Postal Manual.)

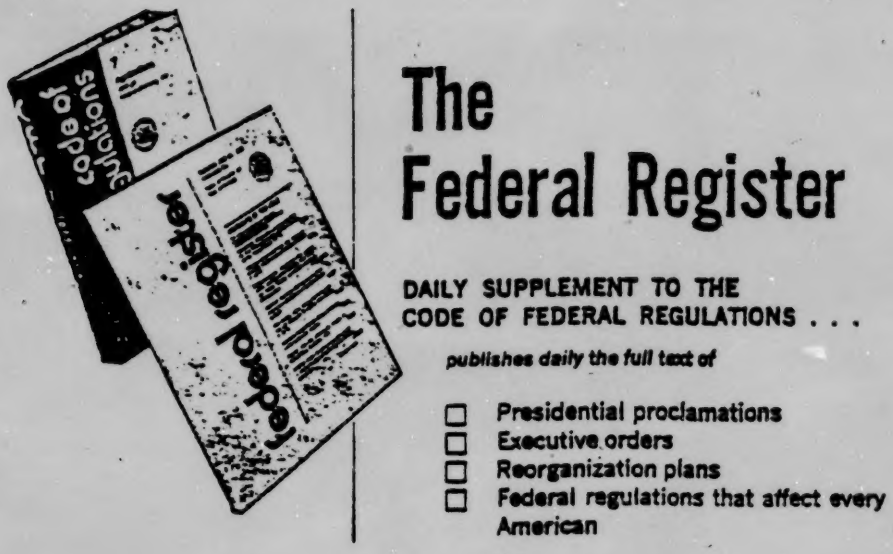

Figure 25-7-2. The Federal Register.

TARIFFS

Another source of regulations is a tariff. A tariff is not an official regulation, but a publication of some agency or association that reprints federal regulations and explains how the organization applies and accepts them. They are binding only on the organization's members; for example, the American Trucking Association, Inc., publishes a tariff. This publication is intended to provide a guide to the federal regulations for their members and to set out procedures that their members must follow to meet the regulations.

INTERNATIONAL REGULATIONS

International organizations, such as the International Atomic Energy Agency (IAEA) and the International Air Transport Association (IATA), issue their own regulations. These regulations are not identical with federal regulations, although DOT regulations have been revised to conform substantially to IAEA rules.

CLASSIFICATION OF RADIOACTIVE MATERIALS (RAM)

For packaging and shipping purposes, RAM can be classified according to its form, quantity, and type. There are two forms of RAM: Special-Form Materials and Normal-Form Materials.

Special-Form Materials are those which, if released from a package, might present some direct radiation hazard, but would present little hazard from radiotoxicity and little possibility of contamination (Figure 25-7-3).

Special-Form Materials will not spill or scatter easily. They may be encapsulated as a sealed source or in some massive solid form. Special-Form criteria are specified in 49CFR §173.398 (the symbol § means paragraph). Material must meet or exceed these criteria before it can be categorized as Special Form. It must be able, for instance, to withstand a drop from a distance of 30 feet; heating in air to a temperature of 1475°F; immersion for 24 hours in water at room temperature; and several other tests before it can receive the Special-Form classification. Once classified as Special-Form Material, larger amounts of material can be placed in packages than otherwise would be permitted; and

more material can be shipped in one package. The classification of material as Special-Form Material is left to the shipper or package designer, who, of course, must be certain that this material meets federal specifications.

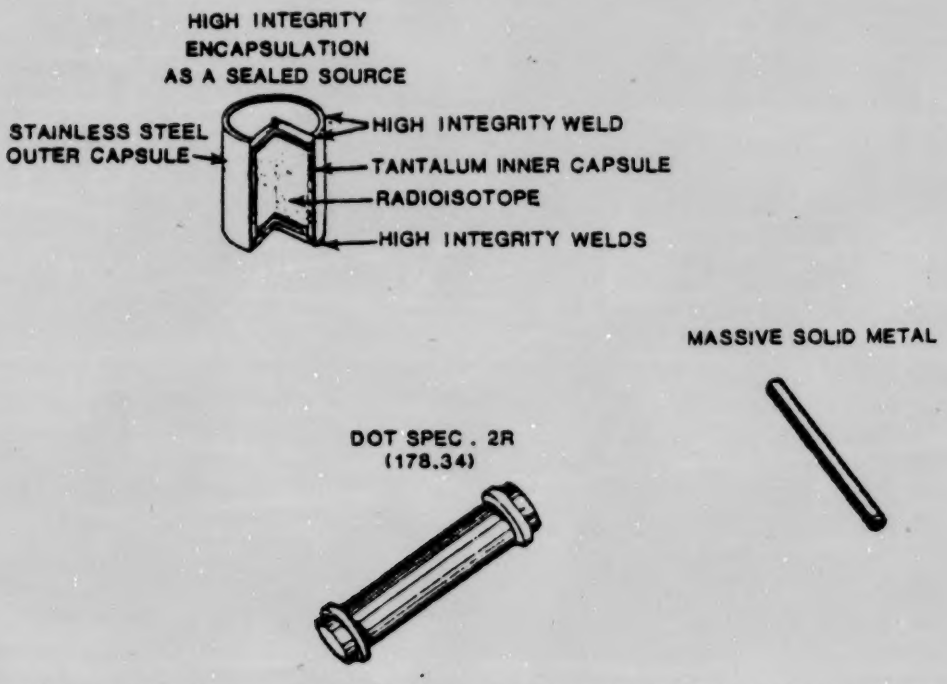

Figure 25-7-3. Special-Form Materials.

Normal-Form Material (Figure 25-7-4) is, simply, any material that does not qualify as Special Form.

WASTE MATERIAL IN PLASTIC BAG

LIQUID IN BOTTLE WITHIN METAL CONTAINER. NO FIRE RESISTANCE

POWDER IN GLASS OR PLASTIC BOTTLE

LOW MELTING. COMBUSTIBLE AND/OR FRANGIBLE SOLID

Figure 25-7-4. Normal Form Materials.

TYPE OF MATERIAL

RAM also is classified according to its type. Normal-Form Material is placed into one of seven transport groups that are ranged according to their radiotoxicity and their relative potential hazard in transportation. Transport group VII contains the least toxic material; group I the most toxic. Regulation 49CFR §173.390 lists the transport groups assigned to radionuclides. When radionuclides are mixed, special procedures, outlined in the same paragraph, are utilized in their classification.

RAM is assigned a Fissile Class in order to provide nuclear criticality safety. Fissile radioactive material is classified into one of three classes discussed later in the module.

TYPE "A" AND TYPE "B" QUANTITIES

The packaging requirements for RAM are structured around the total quantity of material in a package. This quantity usually is expressed in curies, millicuries, or microcuries. Table 25-7-2 relates quantities to packaging requirements.

TABLE 25-7-2
TYPE "A" AND TYPE "B" PACKAGE QUANTITY LIMITS

Transport Group	Type A Quantity (Curies)	Type B Quantity (Curies)
I	0.001	20
II	0.05	20
III	3	200
IV	20	200
V	20	5,000
VI, VII	1,000	50,000
Special Form	20**	5,000

Type "A" quantities can be placed in Type "A" packages; Type "B," in Type "B" packages. A 0.05-curie amount of a transport group II material, for example, would be classified as a Type "A" quantity and packaged in a Type "A" package.

Figure 25-7-5 illustrates some typical Type "A" packaging schemes. Type "A" packaging must be able to withstand "normal" conditions of transport. These "normal" conditions are defined; standards for Type "A" packaging are found in 49CFR §173.398(b). Type "A" packages also have to meet the standards for all packages (§173.24) and for specification 7A; general packaging Type "A" §173.350.

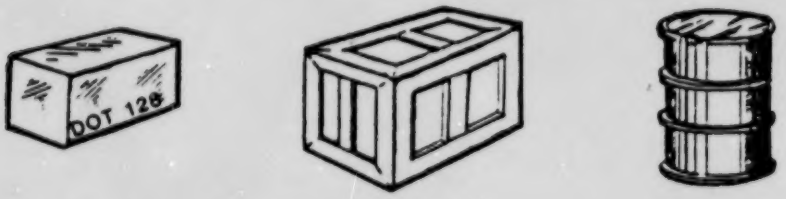

Figure 25-7-5. Typical Type "A" packaging.

Type "A" packaging does not require specific prior approval by DOT, but the shipper of these packages must maintain a certification and safety analysis on file for at least one year.

Type "B" packages must be able to withstand both normal and accident test conditions without loss of contents (Figure 25-7-6). The performance criteria used to test Type "B" packaging are set out in §173.398(c). They include the following:

- A 30-foot free drop onto an unyielding surface.
- A puncture test, which consists of a free drop over 40 inches onto a six-inch diameter steel pin.
- Thermal exposure at 1475°F for 30 minutes.

- Water immersion for eight hours (for fissile-materials packaging only).

All Type "B" packaging designs require prior approval of the U. S. NRC.

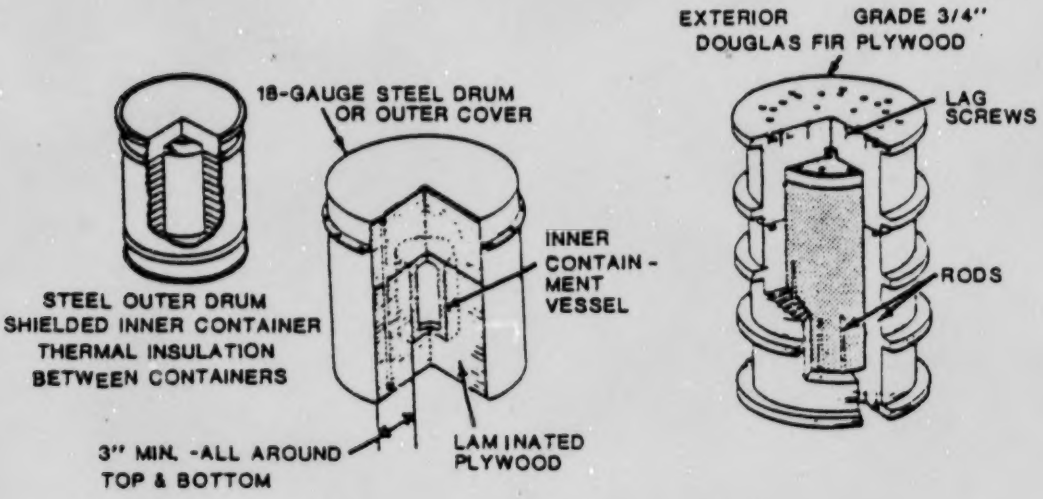

Figure 25-7-6. Typical Type "B" packaging.

LARGE QUANTITIES

Quantities that exceed Type "B" are "Large Quantity" RAM. The most common materials involved as large quantities are the high-curie irradiator sources and irradiated fuel materials. Packaging requirements for these sources involve all the Type "B" packaging requirements, plus provisions for decay-heat dissipation, heavier shielding, and other requirements (§173.395[c]).

SMALL QUANTITIES

Table 25-7-3 lists the activity limits for a material to be qualified as a Small Quantity (also called "Limited," or "Exempt") Material. If a RAM is classified as a Small Quantity, it may be sent by mail and is exempt from general packaging requirements in §173.393 if certain procedures are followed. Small-Quantity Materials must meet the packaging requirements set down in §173.391.

TABLE 25-7-3

ACTIVITY LIMITS FOR SMALL QUANTITIES, MANUFACTURED ARTICLES, RADIOACTIVE DEVICES, AND LOW-SPECIFIC-ACTIVITY MATERIAL

TRANSPORT GROUP	SMALL OR EXEMPT QUANTITIES	MANFT ARTICLES AND RADIOACTIVE DEVICES MAXIMUM QUANTITIES		LOW SPECIFIC ACTIVITY MATERIALS
		PER DEVICE	PER PACKAGE	
I	0.01 mCi	0.0001 Ci	0.0001 Ci	0.0001 mCi/gm
II	0.1 mCi	0.001 Ci	0.05 Ci	0.005 mCi/gm
III	1 mCi	0.01 Ci	3 Ci	0.03 mCi/gm
IV	1 mCi	0.05 Ci	3 Ci	0.3 mCi/gm
V	1 mCi	1 Ci	1 Ci	
VI	1 mCi	1 Ci	1 Ci	
VII	25 Ci	25 Ci	200 Ci	
SPECIAL FORM	1 mCi	0.05 Ci	20 Ci	

Table 25-7-3 also lists activity limits for manufactured articles and radioactive devices such as clocks, instruments, and electronic devices that are exempt from

packaging requirements, provided they meet criteria in §173.391(b).

Low-Specific-Activity Materials are uranium or thorium ores, tritium oxide, and other materials in which the activity is more-or-less uniformly distributed and in which the average estimated concentration per gram does not exceed the specification of §173.389(c).

TRANSPORT INDEX

The Transport Index (TI) is utilized in the computation of the number of packages that may be included in one shipment. This number is placed on the package label to designate the degree of control to be exercised by the carrier during transportation.

The TI is a carefully-computed safety indicator – a measuring unit that takes into account several different factors. For instance, a TI of 1 is assigned to a package that emits a radiation dose of 1 mrem per hour at a distance of 3 feet from its surface, and the TI for any other package varies in proportion to the dose at that standard distance. Thus, a dose of 10 mrem/hr at that point raises the TI for the package to 10; a dose of half a millirem per hour indicates that the TI is 0.5. These indexes are the radiation TI of a package.

Since some nuclear materials are capable of sustaining a nuclear chain reaction, some additional form of control is desirable to ensure that a number of packages that contain these fissile isotopes will not be assembled in one place and thereby produce a critical mass and geometry.

A criticality TI, therefore, may be assigned on the basis of amount, nature, and purity of the fissile material involved; allowances are made if neutron-absorbing material has been incorporated to discourage chain reactions.

The assignment of a criticality TI is a complicated procedure, but the net result is that if the total TI for any vehicle or storage area is 50 or less, there will be an adequate safety margin to avoid any chain reaction.

The radiation TI and the criticality TI rarely will be identical; and when they differ, the package in question always is assigned the larger of the two numbers for shipping purposes. This procedure ensures safety.

The TI of each package must be noted on its warning label, and each package must bear at least two of these labels on its opposite sides.

The maximum limits of radiation for a shipment depend upon the conditions under which the material is transported. Ordinarily, the radiation at the surface of any package is limited by DOT regulations to no more than 200 mrem/hr at 3 feet from the surface of any single package. The normal limit is 10 mrem/hr, which equals a TI of 10.

A TI of only 10 would be very difficult to achieve with a spent fuel cask; therefore, such a shipment is made upon a "sole-use" basis. Thus, when the spent fuel cask is shipped within a closed truck or rail car, the main body of the vehicle itself becomes the "package." The radiation level of the vehicle then must not exceed 200 mrem/hr at its surface.

STOWAGE CONTROL

The TI acts to ensure safety and to provide a format for stowage control (Table 25-7-4) by establishing the distances that must be maintained between the RAM and people, animals, and photographic film.

TABLE 25-7-4
STOWAGE CONTROL FOR RAIL SHIPMENTS

Total Transport Index	Minimum Separation Distance in Feet to Nearest Undeveloped Film	Minimum Distance in Feet to Area of Persons, or Minimum Distance in Feet from Dividing Partition of a Combination Car
None	0	0
0.1 to 10.0	15	3
10.1 to 20.0	22	4
20.1 to 30.0	29	5
30.1 to 40.0	33	6
40.1 to 50.0	36	7

Table 25-7-4 establishes stowage control for rail shipments (§174.700). Tables for other modes of transportation are found in §175.00, §176.700, and §177.842(b).

The TI system, together with tables of separation distances, provides a system whereby the carrier can exercise control over the amount of radiation to which package-handling personnel and other passengers may be exposed.

FISSILE CLASSES

The classification of fissile materials is based upon the TI system:

- FISSILE CLASS I are packages that may be transported in unlimited numbers and in any arrangement, and that require no nuclear criticality safety controls during transportation. For purposes of nuclear criticality safety control, a Transport Index is not assigned to Fissile Class I packages; however, the external radiation levels may require a Transport Index number.
- FISSILE CLASS II packages may be transported together in any arrangement but in numbers that do not exceed any aggregate transport index of 50. For purposes of nuclear criticality safety control, individual packages may have a Transport Index of not less that 0.1 and not more than 10, although the external radiation levels may require a higher Transport Index number (but not to exceed 10). Such shipments require no nuclear criticality safety control by the shipper during transportation.
- FISSILE CLASS III consists of packages that do not meet the requirements of Fissile Class I or

II and that are controlled to provide nuclear criticality safety in transportation by special arrangements between the shipper and the carrier.

Nuclear criticality safety controls are specified by ERDA (now DOE) Manual Chapter 0530.

WARNING LABELS

Each package of radioactive material, unless exempt, must be labeled (§172.403[f]) on two opposite sides, with a distinctive warning label. Each of the three label formats, as described in §172.436 through 172.400 and Figure 25-7-7, bears the unique trefoil symbol.

Figure 25-7-7. Package labels (a), (b), and (c).

These labels alert persons handling packages that the package may require special handling. If the background color of the label is all white (a "white-labeled package"), the radiation is minimal; and nothing special is required for that package. If, however, the background of the upper half of the label is yellow (a "yellow-label package"), a radiation level that requires consideration may exist at the outside of the package; and an indication of what controls must be exercised for that package is related to the Transport Index concept. If the package bears a yellow label having three stripes, the rail or highway vehicle in which it is carried must be placarded. (A placard is simply a sign placed on a vehicle.) The criteria that must be considered by the shipper in choosing the appropriate label are listed in Table 25-7-5. Specific labeling requirements for RAM are given in §172.403.

TABLE 25-7-5

RADIOACTIVE MATERIAL PACKAGES LABELING CRITERIA
DOSE RATE LIMITS

LABEL	AT ANY POINT ON ACCESSIBLE SURFACE OF PACKAGE	AT THREE FEET FROM EXTERNAL SURFACE OF PACKAGE (TRANSPORT INDEX)
"Radioactive-White I"	0.5 mR/hr	0
"Radioactive-Yellow II"	50 mR/hr	1.0 mR/hr
"Radioactive-Yellow III"*	200 mR/hr	10 mR/hr

*Requires vehicle placarding
(This label is mandatory for any Fissile Class III (173.389A) or large quantity package (173.389B), regardless of dose rate levels.)

SHIPPER AND CARRIER REQUIREMENTS

Responsibilities for the packaging and the transporting of RAM may be separated into shipper and carrier requirements.

In general, the shipper is responsible for the following tasks:

- Determine package requirements.
- Package materials.
- Determine TI of materials.
- Label materials and mark packages.
- Complete shipping papers.
- Submit shipper's certification.
- Apply security seal.

The carrier must perform the following tasks:

- Obtain certificate from shipper.
- Apply appropriate placard to vehicle.
- Provide stowage control using TI.
- Report all incidents (fire, accident, etc.).
- Carry all shipping papers.

Some of these responsibilities require additional classification and explanations.

SHIPPING PAPERS AND CERTIFICATION

Certain essential elements of information must be included on the shipping paper description (§172.203[d]). These requirements also apply to packages that contain small quantities and to radioactive devices (§173.391).

The shipping papers must include a shipping certification signed by the shipper.

The following certification statement has been required by Section 172.204(a) since July 1, 1979.

> "This is to certify that the above-named materials are properly classified, described, packaged, marked and are in proper condition for transportation according to the applicable regulations of the Department of Transportation."

SECURITY SEAL

The outside of each radioactive material package must incorporate a security seal, which is not readily breakable and which, while intact, will be evidence that the package has not been illicitly opened (§173.393[b]).

PLACARDING

The carrier must apply the appropriate placard (Figure 25-7-8) on the rail or highway transport vehicle if any RAM package on board bears the "Radioactive YELLOW-III" label (§174.541[b]). When the vehicle is carrying fissile or low-specific-activity uranium hexafluoride, a radioactive placard must be placed on the vehicle. If the vehicle is carrying more than 1,000 lb of this material, a CORROSIVE placard also must be affixed. Placards must be positioned on each side and each end of a vehicle. Requirements for placards are found in §172.50 through §172.558.

Figure 25-7-8. Typical vehicle placard (rail shipments).

THE REPORTING OF INCIDENTS

The carrier, at the earliest practicable moment, must notify the shipper and DOT if fire, breakage, spillage, or suspected radioactive contamination occurs during shipment of radioactive material. Vehicles or buildings in which contamination occurs may not be used again until the dose rate on any surface is less than 5 millirem per hour and until there is no removable radioactive contamination.

If radiological advice or assistance is needed, DOE should be notified. Technical assistance may be obtained by calling the regional office of the Interagency Radio-Logical Assistance Plan. A detailed hazardous-material incident report must be filed after the incident. Paragraphs 171.15, 171.16 and 174.750 outline these procedures.

DETERMINATION OF SHIPPING REQUIREMENTS

Use the below step-by-step procedures to determine the shipping requirements for RAM:

1. Determine proper name of radionuclide from listing §173.390. Note transport group of radionuclide.
2. Determine if RAM will be shipped as Special- or Normal-Form Material.
3. Determine whether material is fissile or nonfissile.
4. Determine quantity of material:

   Consult table §173.391 to determine if RAM is Type "A," Type "B," or Large-Quantity Material. If RAM cannot be classified as any of the quantities above, consult §173.391 to determine if RAM is Limited Quantity.

   Consult §173.389(c) to determine if RAM is a Low-Specific-Activity Material.

   Determine if material is manufactured article or radioactive device.
5. Locate shipping name of material in Hazardous Materials Table (§172.101). If material is not specifically named, look under the general heading of "Radioactive Material." Thorium, plutonium, and uranium metal and its compounds are the only RAM specifically listed in the Table. All RAM not listed specifically must be classified under one of the six "Radioactive Material" headings.
6. From the "Hazardous Materials Table," determine labels required, packaging exceptions, and specific requirements.

7. Follow the specific labeling and packaging requirements for the material, and follow all applicable general labeling and packaging requirements. Part 172 specifies all general marking, labeling, and placarding requirements. Paragraph 172.310 gives specific marking requirements for RAM; §172.403 gives specific labeling requirements. (Subpart C, Part 172, specifies requirements for shipping papers. Security-seal requirements are outlined in §173.393.)

DETERMINATION OF CARRIER REQUIREMENTS

Use the step-by-step procedures listed here as a guide for the determination of carrier requirements.

1. Determine mode of transportation.
2. Obtain shipping papers and certification from shipper (Part 172).
3. Apply appropriate placard to vehicle (§172.504 through Appendix C, Part 172).
4. Provide general and stowage control using TI for —
   - Carriage by rail: consult part 174 for general requirements and §174.700 for stowage requirements.
   - Carriage by aircraft: consult Part 175 for general requirements and §175.700 for stoward requirements.
   - Carriage by vessel: consult "Water Shipments" section of Hazardous Materials Table (§172.101). Read §172.100(h) for explanation of symbols. Part 176 provides general requirements; §176.700, stowage requirements.

- Carriage by public highway: consult Part 177 for general requirements and §177.842 for stowage requirements.

5. Report all incidents (§171.15, 171.16, and 174.750).

EXERCISES

Use 49CFR to find the following information about the radioactive material listed below.

- Transport group.
- Whether material is fissile or nonfissile.
- Whether material is Type "A," Type "B," "Small-Quantity," "Large-Quantity," or "Low-Specific Activity" Material.
- Proper shipping name.
- Hazard class.
- Labels required.
- Paragraph references for packaging exceptions and special requirements.

1. 18 Ci of strontium-90 in normal form.
2. 5 Ci of germanium-71 in normal form.
3. 25 Ci of tritium in normal form and absorbed in solid material.
4. 4 Ci of radium-224 in normal form.
5. 50 milliliters of tritium oxide in aqueous solution with a concentration of 4 millicuries per milliliter in normal form.
6. 30 Ci of tritium-190 in special form.

Use 49CFR and –

7. Find the minimum separation in feet of an area occupied by persons from a package of Radioactive Yellow II material having a Transport Index of 10.7. The package is stowed in a railroad car.
8. Find the minimum separation in feet from a regularly-occupied working space and 10 packages of Radioactive Yellow III material that have a total Transport Index of 28. The material is surrounded by 2 feet of cargo. There is one steel bulkhead between the material and the working space. The material is transported by an ocean-going vessel.

MATERIALS

1 copy of "Title 49, Code of Federal Regulations, Parts 100 to 199."
1 dummy shipping vial, marked "3 Ci Molybdenum-99."
1 dummy Type "A" shipping package.
1 dummy Type "B" shipping package.
Assorted "Radioactive White," "Radioactive Yellow II," and "Radioactive Yellow III" labels.
Wrapping paper.

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Situation: A 3-Ci normal form quantity of molybdenum-99 must be shipped to Kranktown General Hospital, Kranktown, Texas. The shipper is Diversified Atomics Inc., located at 66 Jonesberg Drive, Doeboro, Oklahoma. The molybdenum will be shipped by air and then delivered by truck. The dose, 3 ft from the surface of the package, is 0.01 millirem per hour. The package will not be shipped with other RAM.

1. Use 49CFR and the information above to complete items 1 through 7 of Data Table 25-7-1.
2. By using the completed Data Table and laboratory materials provided and by consulting 49CFR whenever necessary, prepare a dummy shipping package for the 3-Ci quantity of molybdenum-99.
   a. Determine TI of package, and enter in Data Table 25-7-2.
   b. From references cited in items 2 through 5, select, mark, and label package.

DATA TABLE 25-7-1

1.	Proper Shipping Name	_____
2.	Transport Group	_____
3.	Fissile Material? If so, the class	_____
4.	Type Material "A"	_____
	"B"	_____
	Small-Quantity	_____
	Large-Quantity	_____
	Low-Specific-Activity	_____
5.	Hazard Class	_____
6.	Labels required	_____
7.	Paragraph references for packaging exceptions and special requirements	_____

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DATA TABLE 25-7-2

1.	Transport Index – 173.389 Ci _____	
2.	Quantity Type:	
	Limited Quantities	173.391(a)
	Radioactive Devices . . .	173.391(b)
	Type A	173.389(1)
	Type B	173.389(1)
	Large Quantities	173.389(b)
3.	Packaging: General packaging and shipping requirements 173.393 _____	
	Fissile, Radioactive Material . . .	173.396
	RAM Devices	173.391(b)
	RAM Low-Specific-Activity (L.S.A.)	173.392(a), 173.395
	RAM N.O.S.	
	– Type A Quantities	173.395(a)
	– Type B Quantities	173.395(b)
	– Large Quantities	173.395(c)
	RAM Special Form	173.394
	RAM Limited Quantities	173.391(a)
4.	Marking (dual marking if RAM is also some other hazard)	172.300,304, 306, 310
5.	Labeling (2 labels placed on opposite sides of package)(dual labeling if RAM is also some other hazard) . . .	172.400(a) 172.402(a)(1), (b), 172.403, 172.406(c), (e)(1)

White Label I:	Maximum 0.0 TI
Yellow Label II:	Maximum 1.0 TI
Yellow Label III:	Maximum 10.0 TI

REFERENCE MATERIALS

Gibson, R. The Safe Transport of Radioactive Materials. Long Island City, NY: The Pergamon Press, Inc., 44-01 21st St., 1966.

IAEA Regulations for the Safe Transportation of Radioactive Materials. New York: Unipub, Inc., P. O. Box 443.

"Radiological Emergency Operations-Instruction Manual." Springfield, VA: National Technical Information Service.

"Radiological Emergency Operations-Students Manual." Springfield, VA: National Technical Information Service.

Shipping Radioactive Materials. San Francisco: Bechtel Corporation.

"Summary of Federal Regulations for Packaging and Transportation of Radioactive Materials." Springfield, VA: National Technical Information Service, 1971.

1. Write definitions for the following terms:

Tariff.

Normal-Form-Material.

Special-Form-Material.

Transport Group.

Large-Quantity Material.

Limited-Quantity Material.

Type A Quantity.

Type B Quantity.

Type A Packaging.

Type B Packaging.

Small-Quantity Material.

Low-Specific-Activity Material.

Transport Index.

Fissile Class I, II and III.

Yellow-Labeled Package.

White-Labeled Package.

Shippers Certification.

Sole Use.

IAEA Regulations.

Placarding.

Stowage Control.

Security Seals.

2. What entries must be made in the shipping papers that accompany RAM? Use 49CFR and list as least three.

3. What steps should be taken when an accident causes suspected contamination while RAM is being transported?

4. In 49CFR locate the following information about the radioactive material listed below.

   - Transport Group.
   - Whether material is fissile or nonfissile.
   - Whether material is Type "A," Type "B," "Small-Quantity," "Large-Quantity," or "Low-Specific-Activity" material.
   - Proper shipping name.
   - Hazard class.
   - Labels required.
   - Paragraph references for packaging exceptions and special requirements.

   a. 18 Ci ^{234}U in normal form.

   b. 30 Ci neptunium-237 in normal form.

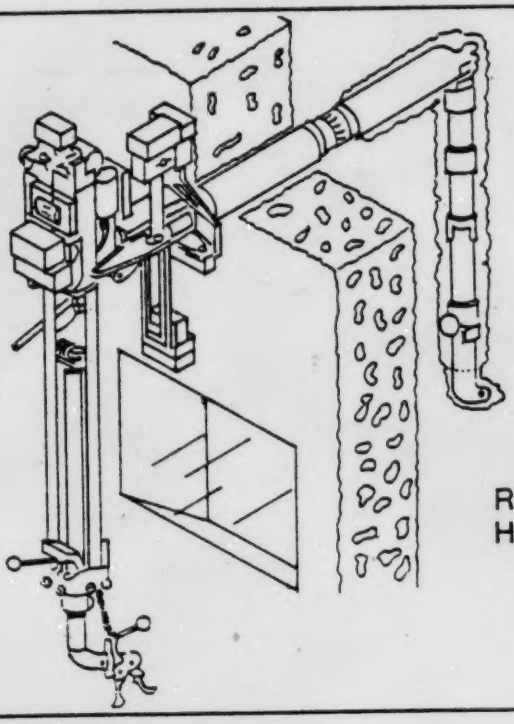
   c. 2,000 Ci strontium-90 in special form.

5. Ten packages of radioactive II RAM having a total TI of 30 are stowed in the cargo hold of an aircraft. Determine the minimum distance in feet from the packages to the dividing partition of the cargo compartment.

NUCLEAR TECHNOLOGY

MODULE 25-8

MANAGEMENT OF EXTERNAL RADIATION CONTAMINATION



RADIOACTIVE MATERIAL HANDLING TECHNIQUES

COURSE 25

ORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

COURSE MODULES

COURSE 25 RADIOACTIVE MATERIAL HANDLING TECHNIQUES

MODULE 25-1	Glove Box Operations - Fundamentals
MODULE 25-2	Glove Box Operations - Advanced
MODULE 25-3	Master/Slave Manipulators - Fundamentals
MODULE 25-4	Master/Slave Manipulators - Advanced
MODULE 25-5	Remote Sampling Techniques
MODULE 25-6	Radioactive Waste Disposal Procedures
MODULE 25-7	Packaging and Monitoring of Radioactive Materials for Shipment
MODULE 25-8	Management of External Radiation Contamination

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INTRODUCTION

Regulations that affect the transportation of radioactive waste material have been issued by the U.S. Department of Transportation (DOT), the U.S. Nuclear Regulatory Commission (NRC), and individual states. Precise knowledge of the external radiation field around the waste container and the amount of surface contamination on the container is required in order to comply with these regulations.

MODULE PREREQUISITES

The student should have successfully completed modules 25-1, 25-2, and 25-3 in this Course and Course 11, "Radiation Detection and Measurement."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Survey radioactive waste containers in order to determine the radiation field strength around the container.
2. List the appropriate action to be taken when given the intensity of the radiation field around a waste container.
3. Perform smear tests to determine whether contamination found on the outside of a waste container is fixed or loose.

4. Determine if the radiations from a smear test are alpha, beta, or gamma radiations or a combination of radiations.
5. Select the appropriate instrument when given a choice of three calibrated instruments and asked to count a sample for a specific alpha, beta, and/or gamma emitter.
6. Given the activity level and other needed information, list the options for corrective action if a smear test does not meet specifications.

When radioactive waste materials are placed into a container, the shielding of the container may or may not provide compliance with regulations. Additionally, the external surface of the container may become contaminated with radioactive material. The area around the container, therefore, must be surveyed and the container subjected to wipe tests to determine whether or not the container may be shipped.

IDENTIFICATION OF THE RADIOACTIVE MATERIAL

Often, both the identity and intensity of the radioactive materials in a particular waste are known, although regrettably, this is not always the case. When the identity of the radionuclide is not known, the first step in the survey of a container of radioactive waste material should be identification of the radioactive species present. Identification may be accomplished by either a sample obtained for laboratory analysis or by the use of a portable gamma X-ray spectrometer. Figure 25-8-1 depicts a typical 100-channel gamma spectrometer.

Figure 25-8-2 shows the gamma spectrum of a single radionuclide. Figure 25-8-3 demonstrates the gamma spectrum of a mixture of three radionuclides.

After the radioactive isotopes present have been identified, the transport group identification must be ascertained. The transport group is any one of seven groups into

which radionuclides are classified according to their radiotoxicity and potential hazard in transportation. This classification can be found in 49CFR170.389(h) and 49CFR170.390(a). The Appendix, beginning on page 24 of this module, provides a series of tables for use in the classification of radioisotopes by transport group.

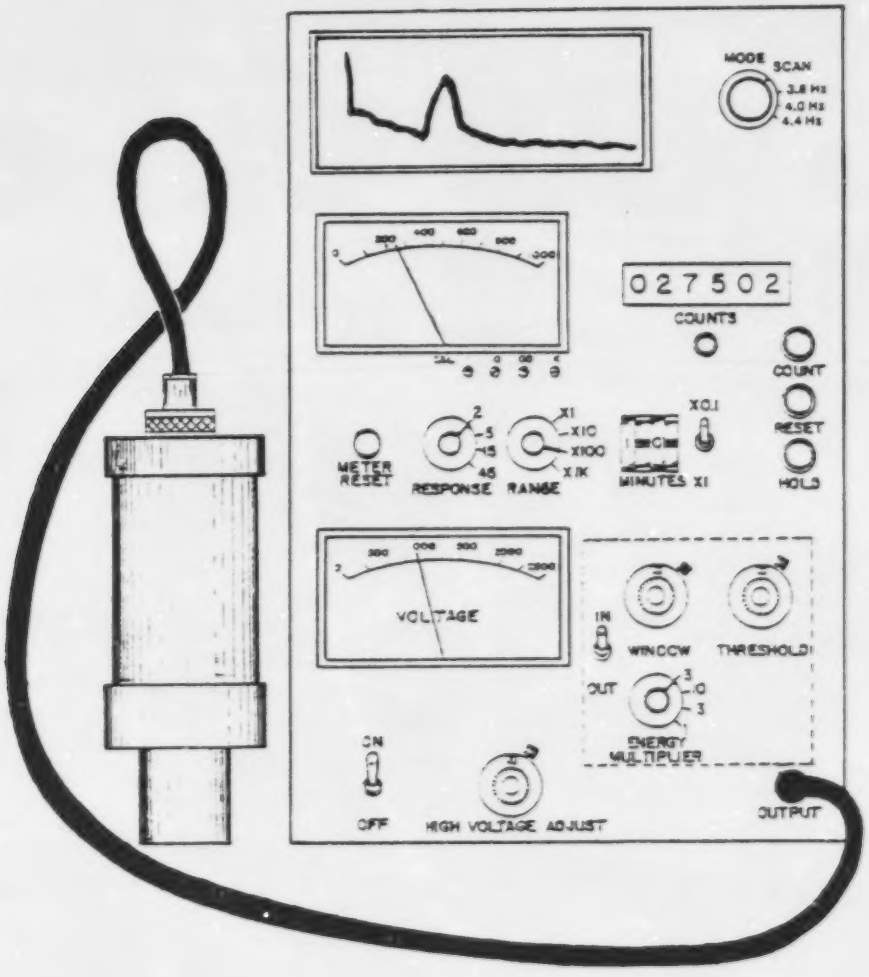

Figure 25-8-1. A portable gamma-ray spectrometer.

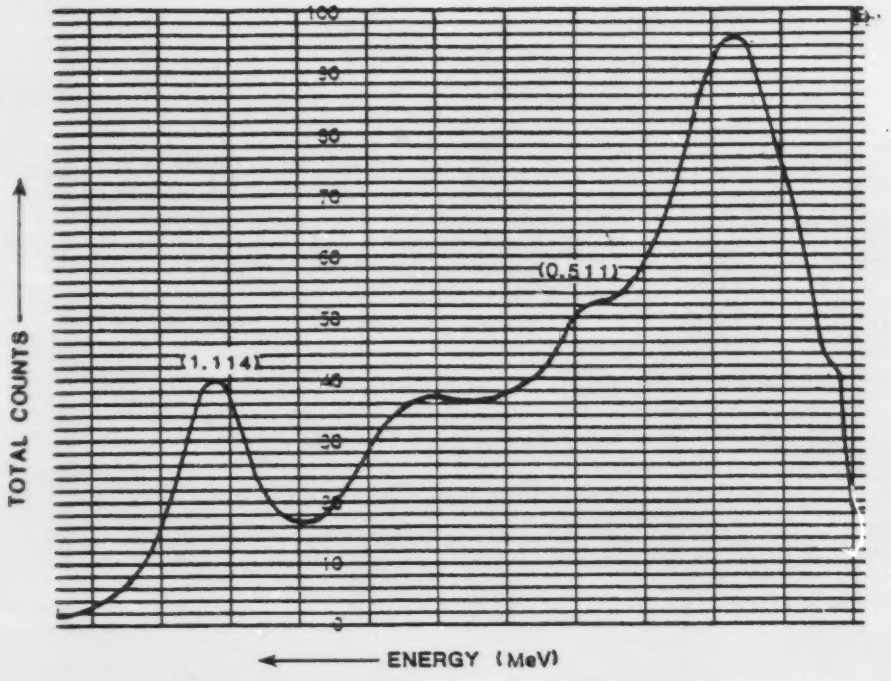

Figure 25-8-2. The gamma spectrum of ^{65}Zn.

Externally-contaminated nonradioactive materials may be considered as low-specific-activity sources if the radioactive contamination averaged over one square meter does not exceed 0.1 microcurie per square centimeter for Group I radionuclides or 1 microcurie per square centimeter for other radionuclides.

External contamination that is not fixed is that in which the contaminant can be removed readily in measurable quantities by the wiping of the contaminated surface with absorbent material. Unfixed external contamination has the following limitations:

- 10 pCi (picocuries) of beta-gamma emitter per square centimeter, and 1 pCi of alpha emitter per square centimeter for all contaminants except natural or depleted uranium or natural thorium.
- 100 pCi of beta-gamma emitter per square centimeter, and 10 pCi of alpha emitter per square centimeter for natural or depleted uranium or natural thorium.

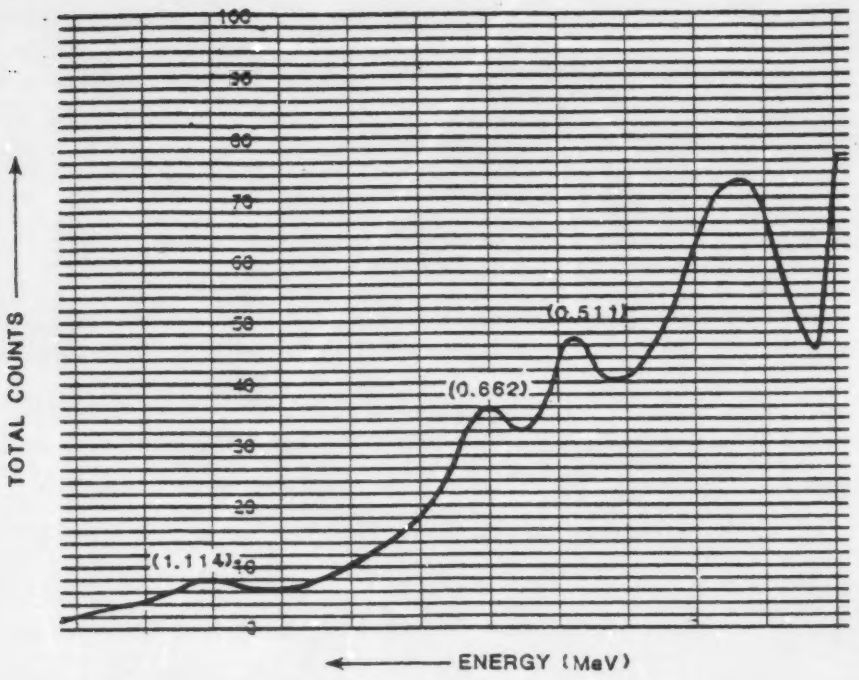

Figure 25-8-3. The gamma spectrum of a mixture of radioisotopes.

EXTERNAL RADIATION FIELD

The external radiation field around a radioactive waste container establishes the transport index, which, in turn, designates the method of transport to be used by the carrier. The transport index is the highest radiation dose rate in millirem per hour at three feet from any accessible surface of the package.

Containers that are to be shipped by any method other than a closed vehicle assigned for the sole use of the consignor, and unloaded by the consignee, must be shielded in such a manner that the dose rate at any exposed surface of the container is a maximum of 200 millirem per hour. The dose rate at a distance of three feet from any exposed surface of the container must not exceed 10 millirem per hour. Containers of radioactive waste material that are shipped in sole-use, closed transport have somewhat higher limitations. Their external radiation field must not exceed 1000 millirem per hour at three feet from the external surface of the package; 200 millirem per hour at any point on the external surface of the vehicle; 10 millirem per hour at six feet from the external surface of the vehicle; and 2 millirem per hour in any normally-occupied position in the car or vehicle.

SURVEY OF THE EXTERNAL RADIATION FIELD

Initial survey of the radiation field around a container of radioactive waste material is conducted best with an ion chamber survey meter. Care should be exercised in se-

lection of the instrument, to ensure that there is sufficient instrument sensitivity to provide an accurate determination of field strength. Figure 25-8-4 depicts a typical ion chamber survey instrument for use in the survey of radiation fields.

Figure 25-8-4
A typical ion chamber survey instrument.

Some type of gaging device should be used to maintain a three-foot distance from the waste container. Innovative technicians may even construct a device to be affixed rigidly to the survey instrument.

Remember that the field survey should be conducted on each individual container, located well away from other containers of radioactive waste. This practice will assure that

the radiation being measured is that emanating from the container in question.

NOTE: BE SURE TO SURVEY THE TOP AND BOTTOM OF THE CONTAINER.

A container of radioactive waste material that has an external radiation field that exceeds 10 millirem per hour requires one of three alternatives for disposition of the container.

The first alternative is decontamination. There is a possibility that the outer surfaces of a container of radioactive waste that exhibits an external radiation field greater than 10 millirem per hour may have become contaminated while the container was being filled. If such contamination has occurred, the logical choice by the technician is to decontaminate the surface and to determine if this procedure reduces the field to within acceptable limits. After decontamination, if the field is still above the 10 millirem/hour limit, the waste material either will have to be repackaged or it may be shipped in a sole-use, closed vehicle, assuming that the external field does not exceed 1000 millirem/hour.

The second alternative, when the external radiation field exceeds 10 millirem per hour, is the removal of some of the radioactive material from the container. This is, in effect, repackaging. An administrative choice must be made considering both economics and compliance, with the compliance feature weighing most heavily.

The third option is shipment of the container in a sole-use, closed vehicle, in which case, the three-foot radiation field must not exceed 1000 millirem/hour. If it does, the material must be repackaged.

THE SURVEYING OF SURFACE ACTIVITY

The second survey required of a container of radioactive waste material involves surface contact. This survey may be conducted with either an ion chamber or with a Geiger-Mueller (GM) type instrument, although the ion chamber is preferable. During the performance of this survey is an opportune time for the technician to locate sites of abnormally high activity for a contamination survey.

The radiation dose at the surface of the container must not exceed 200 millirem per hour if the container is to be shipped by anything other than a sole-use closed vehicle. If it does exceed this amount, there are two options.

As the first option, the external container surface can be checked for surface contamination. If contamination is found, and if the container can be decontaminated to bring the contact radiation level within acceptable limits, the container may be shipped.

The second option occurs either when no external surface contamination can be found which indicates that all activity is coming from within, or when the container cannot be decontaminated. When this occurs, the radioactive waste material must be repackaged before shipment.

SURFACE CONTAMINATION SURVEY

The techniques involved in the surface-contamination survey are identical to those used in the standard smear, or wipe, survey. The surfaces of the container are sampled statistically and specifically for removable surface contamination.

Statistical samples should be taken from the areas of most probable contamination. These areas include the sides of the container, extending approximately six inches around the opening, and any ridges or protrusions extending from the container below the opening.

Smears taken for a contamination survey may be either wet or dry. Dry smears are used more often, although the wet-smear technique is preferred for accuracy. The smear may be taken with either paper or cloth smear blanks, but care must be taken to ensure that the material is not torn. Smear samples for contamination survey must be counted for both alpha and beta-gamma activity. This counting can be accomplished by use of a proportional counter or by use of an alpha counter combined with a Geiger-Mueller counter. Figures 25-8-5 and 25-8-6 depict typical alpha and beta-gamma counters, respectively. If the isotope or isotopes involved are known, the techniques are simplified greatly.

The contaminant limitations, as previously mentioned, are as follows:

- 10 pCi of beta-gamma emitter and 1 pCi of alpha emitter per square centimeter for all contaminates except natural or depleted uranium or natural thorium.
- 100 pCi of beta-gamma emitter and 10 pCi of alpha emitter per square centimeter for natural or deleted uranium or natural thorium.

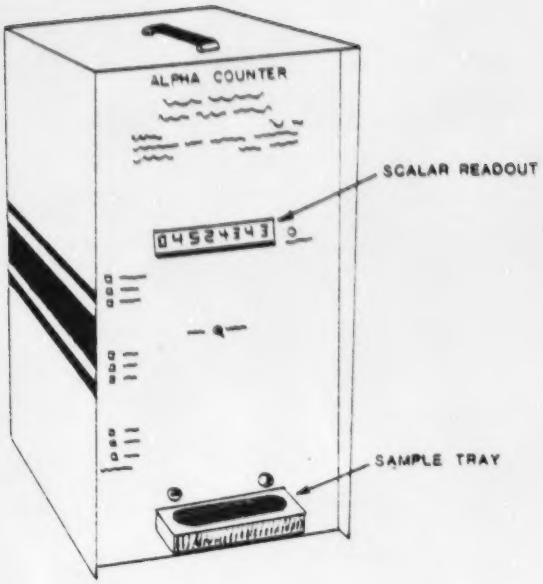

Figure 25-8-5. An alpha scintillation counter.

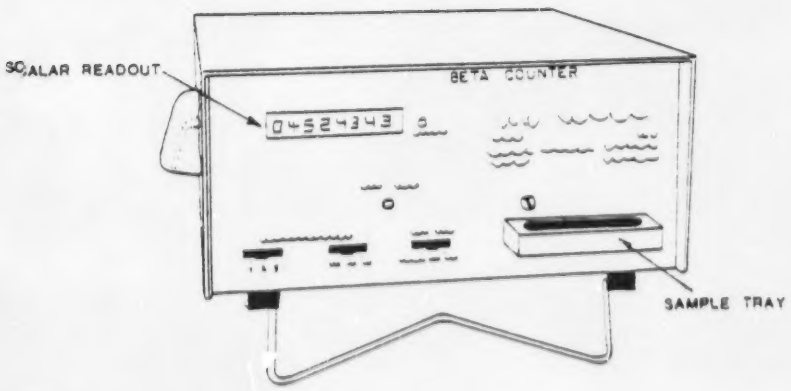

Figure 25-8-6. A beta-gamma counting system.

BACKGROUND AND DESCRIPTION OF SMEAR TESTING

When a surface has become contaminated with a radioactive material, the amount of activity that will rub off the surface onto the hands or clothing of personnel working around that surface should be determined.

A smear test can be made to estimate the amount of removable activity. This is accomplished by firmly wiping a filter disk across the contaminated surface, encompassing an area of approximately 100 cm^2. The filter disc is then mounted and counted, usually in a beta counting system. If alpha activity is suspected, however, it should be counted in an alpha counting system, as well. From the count rates thus obtained, the activity on the filter disc is calculated, by use of the efficiency of the counting system for the particular isotope involved. In the beta counting system, if the identity of the particular isotope is unknown, the sample usually is counted as if it were cobalt-60.

The exception to this procedure occurs when tritium is a possible contaminant. Suspected tritium contamination should be smeared with alcohol wipes or some other solvent that is compatible with liquid scintillation counting. Then the entire wipe should be dissolved in the scintillation cocktail for counting.

PROCEDURE FOR THE COLLECTION OF ROUTINE SMEARS

The establishment of a basis for comparison among different smears requires that the same amount of area be sampled each time. Health physicists have agreed upon 100

square centimeters as the "standard" sample area. Smears are prepared as follows:

1. Obtain a series of clean smear blanks in record holders.
2. Check the smears and holders to ensure that they are numbered sequentially.
3. Place the linenized surface of the first smear into contact with the suspected contaminated surface.
4. Wipe the suspect surface with the smear, using firm contact, covering 100 square centimeters (approximately 4" x 4").
5. Close the smear holder in order that the activity of the smear will not be changed.
6. Repeat the procedure, using sequentially-numbered smear blanks until all suspect areas have been wiped.

PROCEDURE FOR THE DETERMINATION OF SMEAR ACTIVITY

The determination of the activity on each of the smears involves calculations as well as measurement:

1. Calculate the maximum permissible activity in counts per minute based upon the allowable activity and the efficiency of the counting system.
2. Estimate the background activity by placing an uncontaminated smear disc in a planchet and counting it in the system for three minutes.
3. Using the calculated maximum permissible counts per minute and the estimated background activity, determine the required background counting time by referring to the Radiological Health Handbook.

4. Using the same information, determine the most efficient counting time for a sample that contains the maximum permissible activity.
5. Determine the actual background rate by counting the uncontaminated smear disc for the required length of time.
6. Count each smear sample for the time required for the maximum permissible activity.
7. Calculate the net sample count rate of the smear by subtracting the background count rate from the smear count rate.
8. Calculate the activity of the smear from the relationship expressed by Equation 25-8-1:

$$\text{Activity (pCi)} = \frac{\text{Sample Count Rate (cpm)}}{\text{Counter efficiency (cpm/dpm)}} \times \frac{1 \text{ pCi}}{2.22 \text{ dpm}}$$

Equation 25-8-1
(Equation = Eq.)

9. Calculate the activity per square centimeter by dividing the activity by 100 square centimeters.

NONCOMPLIANCE SMEARS

Three alternatives are allowed for a smear sample that does not comply with the maximum limits. The first of these is the taking of another sample, with particular attention paid to the sampling technique.

The second alternative is the decontamination of the area in question. Decontamination must be followed by resampling of the area in question.

The third alternative is the repackaging of the material with the original package considered as waste material. Usually, this alternative is a last resort.

The following example illustrates the calculation of smear activity in picocuries per square centimeter.

EXAMPLE

Given: A smear exhibits a count rate of 100 counts per minute with a background rate of 12 counts per minute. The ^{60}Co efficiency of the counting system is 0.37. The smear area is 100 square centimeters.

Find: The activity of the smear in picocuries per square centimeter.

Solution: Calculations:

Net Count Rate –

$$\text{Count rate} - \text{background count rate} = \text{net count rate}$$

$$100 \text{ cpm} - 12 \text{ cpm} = 88 \text{ cpm.}$$

Smear Activity –

$$\frac{\text{net count rate}}{\text{efficiency } (^{60}Co)} \times \frac{1 \text{ pCi}}{2.22 \text{ dpm}} = \text{activity.}$$

$$\frac{88\text{cpm}}{0.37\ \text{cpm/dm}} \times \frac{1\ \text{pCi}}{2.22\ \text{dpm}} = 107.1\ \text{pCi}.$$

Activity Per Square Centimeter –

Activity/100 cm^2 = A/cm^2

107.1 pCi/100 cm^2 = 1.07 pCi/cm^2.

EXERCISES

1. Use the tables from 49CFR (listed in Appendix) to find the transport group for the following listed radioisotopes:
   - Cobalt-60.
   - Cesium-137.
   - Strontium-90.
   - Mixed fission products.
   - Polonium-210.
   - Radium-226.
   - Iodine-131.
   - Carbon-14.
   - Hydrogen-3.
   - Plutonium-239.
2. A smear sample from a barrel of radioactive waste material exhibits no alpha activity and a net beta-gamma count rate of 391 counts per minute in a beta-gamma counter having a ^{60}Co efficiency of 0.47. What is the activity at the smear site? What should be the disposition of the barrel of radioactive materials?

MATERIALS

Container of radioactive waste materials packaged for shipment (may be simulated). The external surface of the container should be contaminated with the radioisotope in the container.
Portable gamma scintillation spectrometer.
Alpha scintillation counter.
Beta counter.
Package of smear discs.
Package of smear disc holders.
Planchets to fit smear discs.
Charts for the identification of gamma spectra.

PROCEDURES

IDENTIFICATION OF A RADIOISOTOPE BY ITS GAMMA SPECTRUM

CALIBRATION OF THE GAMMA SPECTROMETER

1. Display the gamma spectrum of a sample of ^{137}Cs (0.662 MeV).
2. Determine and record in Data Table 25-8-1 the channel number of the 0.662-MeV photopeak.
3. Display the gamma spectrum of a sample of ^{65}Zn (1.114-MeV).
4. Determine and record the channel number of the 1.114-MeV photopeak.

5. Prepare a plot on linear graph paper of photopeak energy versus channel number. Use the graph in Figure 25-8-7, "Channel energy calibration."

COLLECTION OF THE UNKNOWN GAMMA SPECTRUM

1. Place the gamma scintillation detector near the unidentified gamma emitter – within a few centimeters if possible.
2. Collect the gamma spectrum at least enough to half fill the memory storage of the spectrometer.

IDENTIFICATION OF THE UNKNOWN SPECTRUM

1. Display the gamma spectrum on the spectrometer display.
2. Identify and record the channel number of all channels containing photopeaks. Use Data Table 25-8-2.
3. Use the "Channel energy calibration" graph Figure 25-8-7 to determine the energy of the gamma photons that produce each photopeak.
4. Compare these photon energies with those listed in a chart of radionuclides listed according to gamma photon energies in order to identify the radionuclides present.

COLLECTION AND COUNTING OF A SMEAR SAMPLE

1. Obtain a clean "smear" disc in a smear record holder.
2. Place the clean, linenized surface of the smear disc into contact with the suspected contaminated surface.

3. Place the first two fingers of your hand on the back of the smear record holder, near the center of the smear disc.
4. Using firm pressure of the finger tips, wipe the smear disc over 100 square centimeters of the suspected contaminated surface.
5. Close the smear holder to prevent the activity of the smear from being changed.
6. Place a clean smear disc in a clean planchet, and count the background with a beta counter for three minutes.
7. Record the background total count and count rate in Data Table 25-8-3.
8. Place the contaminated smear disc in a clean planchet, with the contaminated side toward the detector.
9. Count the contaminated smear disc in the beta counter for four minutes.
10. Record the total count and the count rate in Data Table 25-8-3.
11. Subtract the background count rate from the smear count rate to obtain the net count rate. Record this and the following values in Data Table 25-8-4.
12. Divide the net count rate by efficiency factor to obtain the activity in dpm.
13. Divide the activity in dpm by 2.22 dpm to obtain the activity in picocuries.
14. Since the area wiped was 100 cm^2, the activity in picocuries should be divided by 100 to yield activity in picocuries per square centimeter.

DATA TABLE 25-8-1

Isotope	Energy	Channel
^{137}Cs	0.662	
^{65}Zn	1.114	

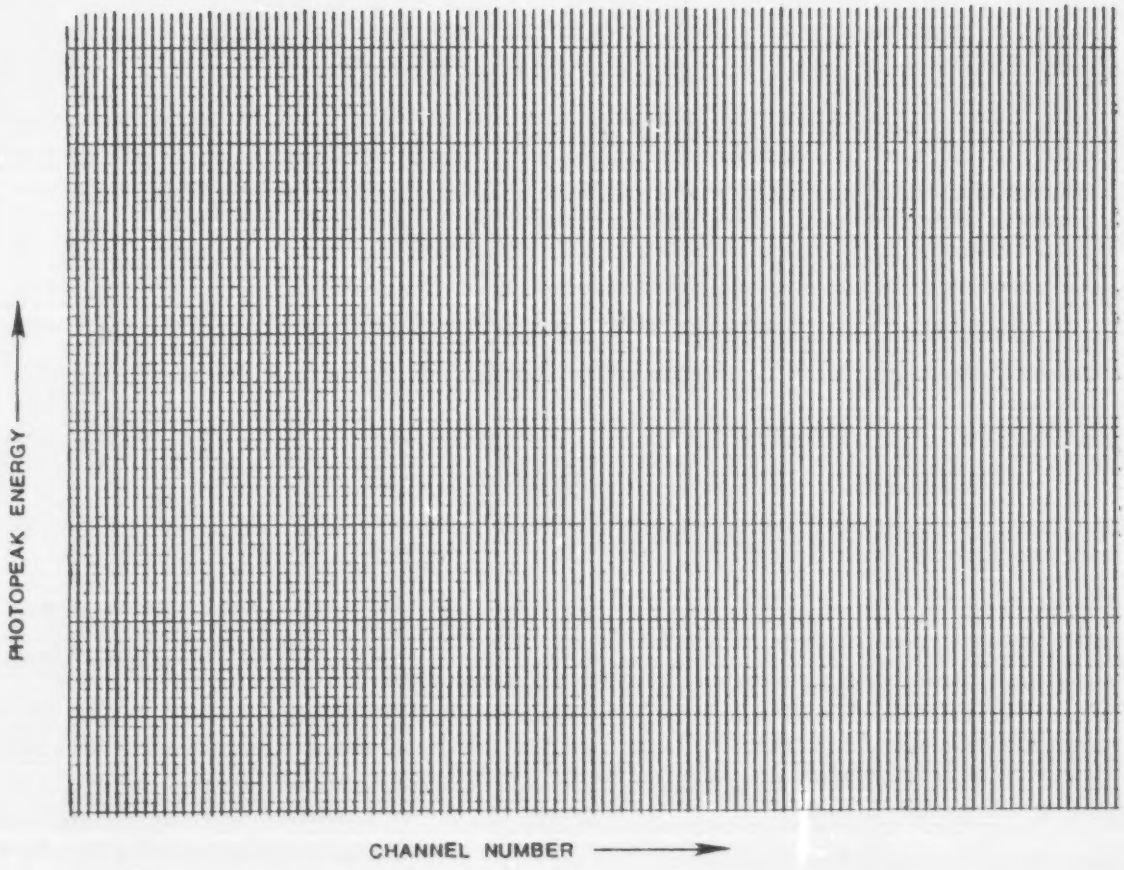

Figure 25-8-7. Channel energy calibration.

DATA TABLE 25-8-2

UNKNOWN SPECTRUM CHANNEL ENERGIES

Channel No.								
Energy MeV								

DATA TABLE 25-8-3

SMEAR SAMPLE COUNT

	Count Time Minutes	Total Count	Count per Minute
Background			
Smear Sample			

DATA TABLE 25-8-4

RESULTS

Smear Number	Corrected Count Rate	^{60}Co Efficiency	Total Activity	Area Activity pCi/cm^2

REFERENCE MATERIALS

Cember, N. Introduction to Health Physics. Exeter, Great Britain: Pergamon Press, Ltd., 1969.

Metcalf, T.B. Radiation Spectra of Radionuclides 1976. Park Ridge, NJ: Noyes Data Corporation, 1976.

U.S. Department of Health, Education, and Welfare. Radiological Health Handbook. Washington, D.C.: U.S. Government Printing Office, 1974.

U.S. Department of Transportation. Code of Federal Regulations, Title 49, Parts 100-199. Washington, D.C.: U.S. Government Printing Office, 1976.

See sections 170.389 and 170.390.

APPENDIX
Classification of Radionuclides into Transport Groups

Classification of Radionuclides into Transport Groups

Symbol	Radionuclide	Group	Symbol	Radionuclide	Group
A	Argon-37	VI	Br	Bromine-82	IV
	Argon-41	II			
	Argon-41 (uncompressed)[a]	V	C	Carbon-14	IV
			Ca	Calcium-45	IV
Ac	Actinium-227	I		Calcium-47	IV
	Actinium-228	I			
			Cd	Cadmium-109	IV
Ag	Silver-105	IV		Cadmium-115m	III
	Silver-110m	III		Cadmium-115	IV
	Silver-111	IV			
			Ce	Cerium-141	IV
Am	Americium-241	I		Cerium-143	IV
	Americium-243	I		Cerium-144	III
As	Arsenic-73	IV	Cf	Californium-249	I
	Arsenic-74	IV		Californium-250	I
	Arsenic-76	IV		Californium-252	I
	Arsenic-77	IV			
			Cl	Chlorine-36	III
At	Astatine-211	III		Chlorine-38	IV
Au	Gold-193	III	Cm	Curium-242	I
	Gold-194	III		Curium-243	I
	Gold-195	III		Curium-244	I
	Gold-196	IV		Curium-245	I
	Gold-198	IV		Curium-246	I
	Gold-199	IV			
			Co	Cobalt-56	III
Ba	Barium-131	IV		Cobalt-57	IV
	Barium-133	II		Cobalt-58m	IV
	Barium-140	III		Cobalt-58	IV
				Cobalt-60	III
Be	Beryllium-7	IV			
			Cr	Chromium-51	IV
Bi	Bismuth-206	IV			
	Bismuth-207	III	Cs	Cesium-131	IV
	Bismuth-210(Ra.E)	II		Cesium-134m	III
	Bismuth-212	III		Cesium-134	III
				Cesium-135	IV
Bk	Berkelium-249	I		Cesium-136	IV
				Cesium-137	III

[a] Uncompressed shall mean at a pressure not exceeding one atmosphere absolute at 0°C. and mean sea level.

Classification of Radionuclides into Transport Groups (continued)

Symbol	Radionculide	Group	Symbol	Radionculide	Group
Cu	Copper-64	IV	I	Iodine-134	IV
				Iodine-135	IV
Dy	Dysprosium-154	III			
	Dysprosium-165	IV	In	Indium-113m	IV
	Dysprosium-166	IV		Indium-114m	III
				Indium-115m	IV
Er	Erbium-169	IV		Indium-115	IV
	Erbium-171	IV			
			Ir	Iridium-190	IV
Eu	Europium-150	III		Iridium-192	III
	Europium-152	III		Iridium-194	IV
	Europium-152m	IV			
	Europium-154	II	K	Potassium-42	IV
	Europium-155	IV		Potassium-43	III
F	Fluorine-18	IV	Kr	Krypton-85m	III
				Krypton-85m (uncompressed) (a)	V
Fe	Iron-55	IV			
	Iron-59	IV		Krypton-85	III
				Krypton-85 (uncompressed) (a)	VI
Ga	Gallium-67	III			
	Gallium-72	IV		Krypton-87	II
				Krypton-87 (uncompressed) (a)	V
Gd	Gadolinium-153	IV			
	Gadolinium-159	IV			
			La	Lanthanum-140	IV
Ge	Germanium-71	IV			
			Lu	Lutetium-172	III
H	Hydrogen-3 (see T-Tritium)			Lutetium-177	IV
			M.f.p.	Mixed fission products	II
Hf	Hafnium-181	IV			
Hg	Mercury-197m	IV	Mg	Magnesium-28	III
	Mercury-197	IV			
	Mercury-203	IV	Mn	Manganese-52	IV
				Manganese-54	IV
Ho	Holmium-166	IV		Manganese-56	IV
I	Iodine-124	III	Mo	Molybdenum-99	IV
	Iodine-125	III			
	Iodine-126	III	Na	Sodium-22	III
	Iodine-129	III		Sodium-24	IV
	Iodine-131	III			
	Iodine-132	IV			
	Iodine-133	III			

Classification of Radionuclides into Transport Groups (continued)

Symbol	Radionuclide	Group	Symbol	Radionuclide	Group
Nb	Niobium-93m	IV	Pt	Platium-191	IV
	Niobium-95	IV		Platium-193	IV
	Niobium-97	IV		Platium-193m	IV
				Platium-197m	IV
Nd	Neodymium-147	IV		Platium-197	IV
	Neodymium-149	IV			
			Pu	Plutonium-238	I
Ni	Nickel-56	III		Plutonium-239	I
	Nickel-59	IV		Plutonium-240	I
	Nickel-63	IV		Plutonium-241	I
	Nickel-65	IV		Plutonium-242	I
Np	Neptunium-237	I	Ra	Radium-223	II
	Neptunium-239	I		Radium-224	II
				Radium-226	I
Os	Osmium-185	IV		Radium-228	I
	Osmium-191m	IV			
	Osmium-191	IV	Rb	Rubidium-86	IV
	Osmium-193	IV		Rubidium-87	IV
				Rubidium natural	IV
P	Phosphorus-32	IV			
			Re	Rhenium-183	IV
Pa	Protactinium-230	I		Rhenium-186	IV
	Protactinium-231	I		Rhenium-187	IV
	Protactinium-233	II		Rhenium-188	IV
				Rhenium natural	IV
Pb	Lead-203	IV			
	Lead-210	II	Rh	Rhodium-103m	IV
	Lead-212	II		Rhodium-105	IV
Pd	Palladium-103	IV	Rn	Radon-220	IV
	Palladium-109	IV		Radon-222	II
Pm	Promethium-147	IV	Ru	Ruthenium-97	IV
	Promethium-149	IV		Ruthenium-103	IV
				Ruthenium-105	IV
Po	Polonium-210	I		Ruthenium-106	III
Pr	Praseodymium-142	IV	S	Sulphur-35	IV
	Praseodymium-143	IV			

Classification of Radionuclides into Transport Groups (continued)

Symbol	Radionuclide	Group
Sb	Antimony-122	IV
	Antimony-124	III
	Antimony-125	III
Sc	Scandium-46	III
	Scandium-47	IV
	Scandium-48	IV
Se	Selenium-75	IV
Si	Silicon-31	IV
Sm	Samarium-145	III
	Samarium-147	III
	Samarium-151	IV
	Samarium-153	IV
Sn	Tin-113	IV
	Tin-117m	III
	Tin-121	III
	Tin-123	IV
Sr	Strontium-83m	IV
	Strontium-85	IV
	Strontium-89	III
	Strontium-90	II
	Strontium-91	III
	Strontium-92	IV
T	Tritium	IV
	Tritium-activated luminous paint, tritium gas, or adsorbed on a solid carrier	VII
Ta	Tantalum-182	III
Tb	Terbium-160	III
Tc	Technetium-96m	IV
	Technetium-96	IV
	Technetium-97m	IV
	Technetium-97	IV
	Technetium-99m	IV
	Technetium-99	IV
Te	Tellurium-125m	IV
	Tellurium-127m	IV
	Tellurium-127	IV
	Tellurium-129m	III
	Tellurium-129	IV
	Tellurium-131m	III
	Tellurium-132	IV
Th	Thorium-227	II
	Thorium-228	I
	Thorium-230	I
	Thorium-231	I
	Thorium-232	III
	Throium-234	II
	Thorium natural	III
Tl	Thallium-200	IV
	Thallium-201	IV
	Thallium-202	IV
	Thallium-204	III
Tm	Thulium-168	III
	Thulium-170	III
	Thulium-171	IV
U	Uranium-230	II
	Uranium-232	I
	Uranium-233	II
	Uranium-234	II
	Uranium-235	III
	Uranium-236	II
	Uranium-238	III
	Uranium natural	III
	Uranium enriched	III
	Uranium depleted	III

Classification of Radionuclides into Transport Groups (continued)

Symbol	Radionuclide	Group
V	Vanadium-48	IV
	Vanadium-49	III
W	Tungsten-181	IV
	Tungsten-185	IV
	Tungsten-187	IV
Xe	Xenon-125	III
	Xenon-131m	III
	Xenon-131m (uncompressed) (a)	V
	Xenon-133	III
	Xenon-133 (uncompressed) (a)	VI
	Xenon-135	II
	Xenon-135 (uncompressed) (a)	V
Y	Yttrium-88	III
	Yttrium-90	IV
	Yttrium-91m	III
	Yttrium-91	III
	Yttrium-92	IV
	Yttrium-93	IV
Yb	Ytterbium-175	IV
Zn	Zinc-65	IV
	Zinc-69m	IV
	Zinc-69	IV
Zr	Zirconium-93	IV
	Zirconium-95	III
	Zirconium-97	IV

(a) Uncompressed shall mean at a pressure not exceeding one atmosphere absolute at 0°C. and mean sea level.

1. Write a procedure for a survey of a container of radioactive waste materials before shipment. Include equipment and specific tests to be made.

2. What are the options available if the radiation field around a container of radioactive waste is found to be 125 millirem per hour at a distance of three feet?

3. Write a procedure for the performance of a smear test.

4. What instrument should be used to determine whether the radiations present in a sample are alpha, beta, or gamma radiations?

5. Given a choice of an alpha scintillation counter, a Geiger-Mueller counter, or a pulse height analyzer equipped with a photomultiplier tube and a sodium iodide crystal, which instrument would be best suited to count a smear sample known to contain ^{14}C?

6. What actions must be taken if a contamination smear sample indicates an activity level of 1.7 microcuries of cobalt-60 per square centimeter on the external surface of a barrel of radioactive waste material to be shipped?

NUCLEAR TECHNOLOGY

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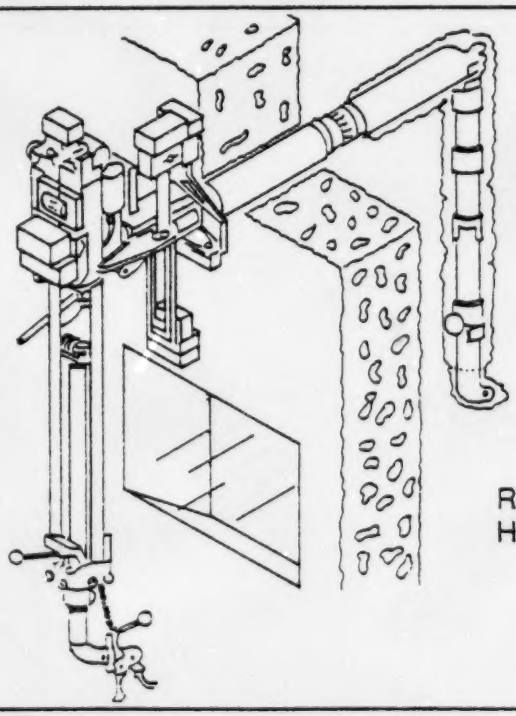

RADIOACTIVE MATERIAL HANDLING TECHNIQUES

COURSE 25

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

NUCLEAR TECHNOLOGY SERIES

INDEX

for

COURSE 25, RADIOACTIVE MATERIAL HANDLING TECHNIQUES (EIGHT MODULES)

NOTE: Each module in this Course is numbered separately, and the page numbers begin with page 1 in each module. Therefore, this Index lists for each entry the module number (underlined), followed by a comma and the page number. Figures and tables are listed by their numbers, followed by the module and page number in parentheses. A Master Index is available in a separate volume. This general index merges all index entries from the 35 Nuclear Courses. It is a valuable research tool, with which the student or researcher can locate all the references to any subject within the 35 Courses.

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